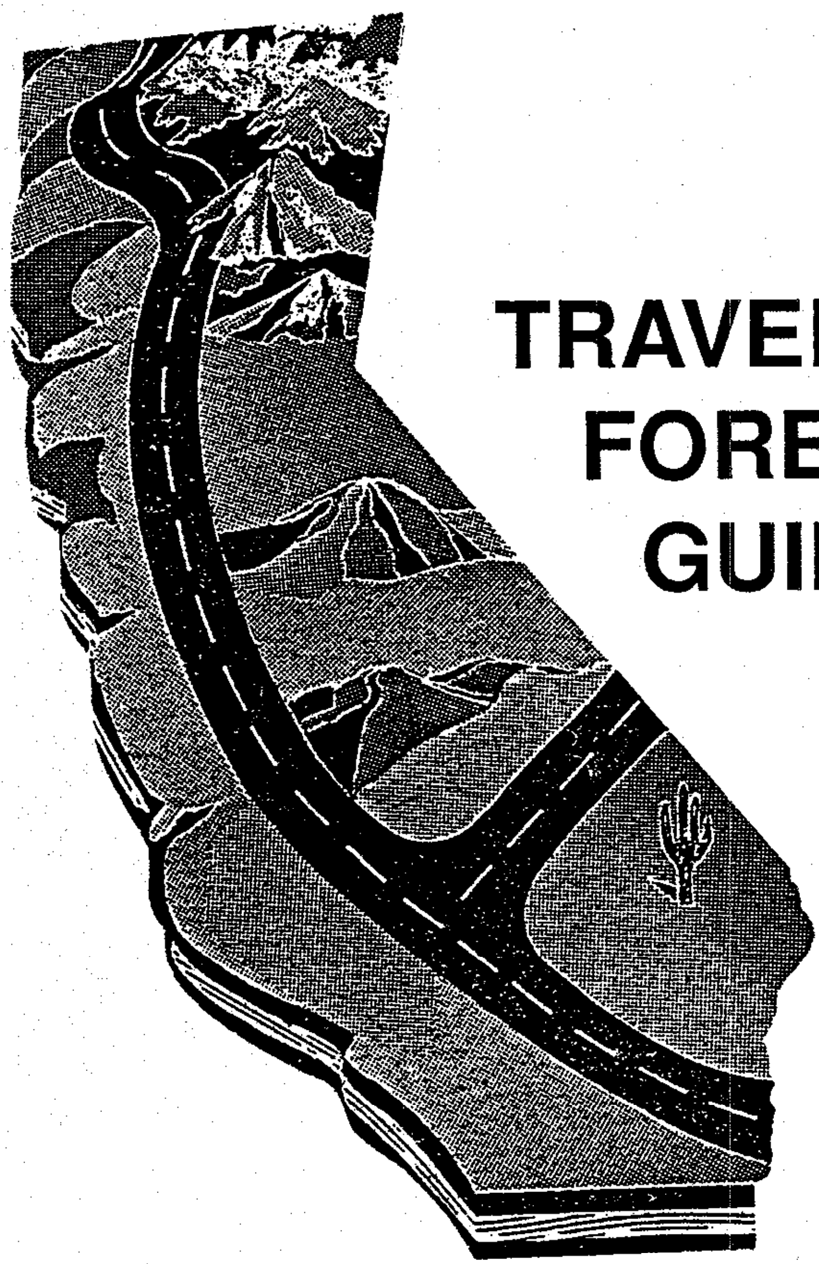
Travel



TRAVEL FORECASTING GUIDELINES

CALIFORNIA DEPARTMENT OF TRANSPORTATION

Caltrans

November 1992

REFERENCES

CHAPTER 2: REFERENCES

California DOT, "California Statewide Traffic Model 1987 Base Year Update", Office of Traffic Improvement, November 1991.

California DOT, "California Motor Vehicle Stock, Travel and Fuel Forecast", Division of Transportation Planning (annual).

California Employment Development Dept. reports, by county, "Size of Firm", (various dates).

Green, Rodney D. and Praeger Publishers, "Forecasting with Computer Models", 1985.

FHWA, "Calibration and Adjustment of System Planning Models", December 1990.

FHWA, "UTPS Highway Network Development Guide", January 1983.

TRB, "Forecasting the Basic Inputs to Transportation Planning at the Zonal Level", NCHRP Report #328, June 1990.

TRB, "Forecasting Inputs to Transportation Planning", NCHRP Report #266, December 1983

TRB, "Quick Response Urban Travel Estimation Techniques and Transferable Parameters", NCHRP Special Report 187, 1978.

UMTA, "Procedures and Technical Methods for Transit Project Planning", September 1986.

UMTA, "Transit Network Analysis: INET", July 1979.

US Dept. of Commerce, "BEA Regional Projections to 2040", Bureau of Economic Analysis, 1990 (3 vols.).

CHAPTER 3: REFERENCES

Bates, Dr. J.J. and Dasgupta, Dr. M, "Review of techniques of travel demand analysis: Interim Report", Transport and Road Research Laboratory, Crowthorne, Berkshire, 1990.

Ben-Akiva, Moshe E. and Bolduc, Denis, "Approaches to Model Transferability: The Combined Transfer Estimator", for presentation at the Transportation Research Board Annual Meeting, Washington, D.C., 1987.

Ben-Akiva, Moshe E., and Lerman, Steven R., "Discrete Choice Analysis: Theory and Application to Travel Demand," M.I.T. Press, Cambridge, MA, 1985.

Ben-Akiva, Moshe E. and Steven R. Lerman, "Disaggregate Travel and Mobility Choice Models and Measures of Accessibility", Proceedings of the Third International Conference of Behavioral Travel Modelling, Australia, 1977.

COMSIS Corporation, "Quick Response Urban Travel Estimation Techniques and Transferable Parameters", National Cooperative Highway Research Program Report 187, Transportation Research Board, Washington, D.C., 1978.

Federal Highway Administration, "Calibration and Adjustment of System Planning Models", U.S. Department of Transportation, Publication No. FHNA-ED-90-015, 1990.

Institute of Transportation Engineers, Trip Generation, 5th Edition, Washington, D.C., 1991.

JHK & Associates, "Highway Traffic Data for Urbanized Area Project Planning and Design", National Cooperative Highway Research Program Report No. 255, Transportation Research Board, Washington, D.C., 1982.

Kitamura, Ryuichi, "Sequential, History-Dependent Approach to Trip-Chaining Behavior", Transportation Research Record 944, Transportation Research Board, Washington, D.C., 1983.

Koppleman, Frank S., Kuah, Geok-Koon, Wilmot, Chester G., "Alternative Specific Constant and Scale Updating for Model Transferability with Disaggregate Data", 1984.

McFadden, Daniel, "Conditional Logit Analysis of Qualitative Choice Behavior, in Frontiers in Econometrics, editor Paul Zarembka, Academic Press, New York, 1973.

Ortuzar, J. de D., and Willumsen, L.G., Modeling Transport, John Wiley & Sons, West Sussex, England, 1990.

Prashker, Joseph N., "Multi-Path Capacity-Limited Transit Assignment", Transportation Research Record 1283, Transportation Research Board, Washington, D.C., 1990.

Pratt, R.H., "Development and Calibration of Mode Choice Models", Houston Urban Region.

Schultz, Gordon W., "Development of a Travel Demand Model Set for the New Orleans Region", Transprotation Forecasting: Analysis and Quantitative Methods, Transportation Research Record 944, Transportation Research Board, Washington, D.C., 1983.

Stopher, Peter R. and Meyburg, Arnim H., Urban Transportation Modeling and Planning, Lexington Books, D.C. Heath & Company, Lexington, MA, 1975.

Urban Mass Transportation Administration, "Procedures and Technical Methods for Transit Project Planning", U.S. Department of Transportation, PB91-183152, Washington, D.C., 1990.

Voorhees, Alan M. and Associates, "Factors and Trends in Trip Length", NCHRP No. 48, 1968.

Weisbrod, Daly, Trip-Chaining "Primary Destination Tour Approach to Travel Demand Modeling An Empirical Analysis and Modeling Implications", 1979.

CHAPTER 4: REFERENCES

Guensler, Randall, Daniel Sperling, and Paul P. Jovanis (1991); "Uncertainty in the Emission Inventory for Heavy-Duty Diesel Powered Trucks," Institute of Transportation Studies Report 91-01; University of California, Davis, Department of Civil Engineering; March 1991.

Horowitz, Joel, Air Quality Analysis for Urban Transportation Planning, the MIT Press, Cambridge, Massachusetts, 1982.

JHK & Associates and Sierra Research, "Overview of the Travel and Emissions Estimation Procedures for the San Joaquin Valley Emissions Inventory" (draft), prepared for the California Air Resources Board and the San Joaquin Valley Air Pollution Study Joint Powers Agency, Sacramento, California, June 1990.

Loudon, William R., and Malcolm M. Quint, "Integrated Software for Transportation Emissions Analysis", prepared for presentation at American Society of Civil Engineers, Conference of Transportation Planning and Air Quality, Santa Barbara, California, July 1991.

Seitz, Leonard E.,"California Methods for Estimating Air Pollution Emissions for Motor Vehicles", California Department of Transportation (Caltrans), Division of Transportation Planning, Office of Transportation Analysis, Sacramento, California, 1989a.

Seitz, Leonard E. ,"Direct Travel Impact Model: Coding Instructions", California Department of Transportation (Caltrans), Division of Transportation Planning, Office of Transportation Analysis, Sacramento, California, 1989b.

CHAPTER 5: REFERENCES

Bates, Dr. J.J, and Dasgupta, Dr. M., "Review of Techniques of Travel demand Analysis: Interim Reports," Transport and Road Research Laboratory, Crowthorne, Berkshire, 1990.

Californians for Better Transportation and the Bay Area Council , "Congestion Management Programs: Theory Hits the Streets," January, 1992.

"Congestion Management Program: Resource Handbook," November, 1990.

Kitamura, Ryuichi, "Sequential, History-Dependent Approach to Trip-chaining Behavior," Transportation Research Record 944, Transportation Research Board, Washington, D.C., 1983.

Kollo, Hanna P.H., and Purvis, Charles L., "Regional Travel Forecasting Model System for the San Francisco Bay Area," Transportation Research Record 1220, Transportation Research Board, Washington, D.C., 1989.

Stopher, P.R., "Travel Forecasting Methodology: Transfer of Research into Practice," Australian Road Research 15:3, September, 1985.

STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION

TRAVEL FORECASTING GUIDELINES

Prepared in Cooperation
with the
U.S. Department of Transportation
Federal Highway Administration

Prepared by:

JHK & Associates
2000 Powell Street, Suite 1090
Emeryville, CA 94608

in association with

Dowling Associates

November 1992

ACKNOWLEDGEMENTS

This document is the result of work performed by JHK & Associates in association with Dowling Assoc., under contract to the California Department of Transportation. Throughout the preparation of this report, individuals from several agencies have provided valuable impetus to this project. At the outset, the consultant formed an Advisory Committee to contribute suggestions and comments for the betterment of the Guidelines. The Advisory Committee was composed of representatives from the following agencies:

California Department of Transportation
California Air Resources Board
Southern California Association of Governments
Metropolitan Transportation Commission
San Diego Association of Governments
Orange County Environmental Management Agency
Kern Council of Governments

TABLE OF CONTENTS

Page

CHAPTER 1: INTRODUCTION

1.1 PROJECT OVERVIEW AND OBJECTIVES 1

1.2 SUGGESTED USE OF THE GUIDELINES 2

1.3 LEGISLATIVE AND PROCEDURAL REQUIREMENTS FOR USE OF THE MODEL 4

1.4 OUTLINE OF THE REPORT 6

CHAPTER 2: INPUT DATA AND ASSUMPTIONS

2.1 OVERVIEW 7

2.2 SOCIO-ECONOMIC DATA 8

2.2.1 Household, Income, and Auto Ownership 8
2.2.2 Employment Information 12
2.2.3 Conformity for Sub-Area Model 14

2.3 SPECIAL TRIP GENERATORS DATA 14

2.4 EXTERNAL STATIONS AND TRIPS 15

2.5 NETWORK DATA

2.5.1 Overview 16
2.5.2 Transportation Analysis Zones 16
2.5.3 Highway Networks 18
2.5.4 Advanced Practice: Transit Networks 21

2.6 TRAVEL COST INFORMATION 24

2.6.1 Auto Operating Costs 24
2.62 Parking Costs 25

2.63 Transit Fares 25
2.6.4 Tolls 25

TABLE OF CONTENTS (Continued)

Page

2.7 CALIBRATION AND VALIDATION DATA 26

2.7.1 Traffic Counts 28
2.7.2 Highway Travel Speeds/Travel Times 28
2.7.3 Origin-Destination and Trip Length Information 28
2.7.4 Vehicle Occupancy 29
2.7.5 Local Trip Generation Surveys 29

CHAPTER 3: TRAVEL DEMAND MODELING

3.1 FOUR-STEP DEMAND MODELING OVERVIEW 30

3.2 TRIP GENERATION 33

3.2.1 Objective 33
3.2.2 Modeling Specifications 34
Trip Purposes 35
Home-Based Trip Production Models 36
Home-Based Trip Attraction Models 36
Non-Home-Based Models 37
State-of-the-Practice Methods 37
Internal-External and External-Internal Trips 41
External Trips 41
Special Generator Trips 41
3.2.3 Calibration 41
3.2.4 Validation 43

3.3 TRIP DISTRIBUTION 45

3.3.1 Objective 45
3.3.2 Model Specifications 45
State-of-Practice Methods 45
Impedance 49
K-Factors 50
Intrazonal trips 50
3.3.3 Calibration 51
3.3.4 Validation 51

TABLE OF CONTENTS (Continued)

Page

3.4 MODE CHOICE 52

3.4.1 Objective 52
3.4.2 Model Specifications 52
Discrete Choice Models 53
Incremental Mode-Choice Models 58
3.4.3 Calibration 58
3.4.4 Validation 59

3.5 TRIP ASSIGNMENT 59

3.5.1 Objective 59
3.5.2 Model Specifications 60
Impedance 60
Capacity 60
Highway Assignment 61
HOV Assignments 62
Transit Assignment 62
3.5.3 Calibration and Validation 65

3.6 TIME-OF-DAY DISTRIBUTION 67

3.7 FORECASTS 69

3.8 FEEDBACK MECHANISMS 71

3.9 MODEL APPLICATIONS 74

3.9.1 Analysis of Transportation Control Measures 74
3.9.2 Congestion Management 74

3.10 REGIONAL AND SUBREGIONAL MODELING RELATIONSHIP 75

3.11 MODEL DOCUMENTATION 76

CHAPTER 4: EMISSION INVENTORY NEEDS

4.1 OVERVIEW 77

4.1.1 Historical Development of Emission Estimation Procedures 77
4.1.2 Sensitivity of Emissions to Travel Characteristics 78
4.1.3 California's Direct Travel Input Model 82

TABLE OF CONTENTS (Continued)

Page

4.2 TRIP VOLUMES BY PURPOSE AND TIME PERIOD

4.2.1 Trip Purpose Categories 85
4.2.2 Time Period Definitions 86
4.2.3 Travel with External Trip Ends 87
4.2.4 Special Forecasts 87
4.2.5 Comprehensive Coverage of Trips 88

4.3 VEHICULAR SPEEDS

4.3.1 Relationship Between Speed and Emission Rate 89
4.3.2 Consistent Use of Speed 90
4.3.3 Averaging of Speeds 90
4.3.4 Methods for Validating Speed Estimation 92

4.4 PRE-START AND POST-PARK PARAMETERS 92

CHAPTER 5: RESEARCH AND RECOMMENDATIONS

5.1 INSTITUTIONAL AND RESOURCE REQUIREMENTS

5.1.1 Legislative Requirements 94
5.1.2 Modeling Coordination Between Agencies 97
5.1.3 Consistency of Modeling Approach 97

5.2 DATA NEEDS

5.2.1 Land Use and Socioeconomic Data 97
5.2.2 Network/Supply Information 98
5.2.3 Cost Information 99

5.3 MODEL IMPROVEMENTS

5.3.1 Modeling Assumptions 99
5.3.2 Data Needs for Models 99
5.3.3 Four-Step Demand Model Improvements 100
5.3.4 Other Issues 102

TABLE OF CONTENTS (Continued)

Page

5.4 EMISSION INVENTORY AND OTHER AIR QUALITY NEEDS

5.4.1 Comprehensive Cover of Trips 103
5.4.2 Prediction of Starts and Parks 103
5.4.3 Modeling of Weekend and Summertime Travel 103
5.4.4 Enhancement of Emission Rates 104

5.5 TRAFFIC MANAGEMENT AND DEMAND MANAGEMENT ANALYSIS NEEDS

5.5.1 Traffic Management 104
5.5.2 Demand Management 105

5.6 INTERFACE BETWEEN LAND USE AND TRANSPORTATION

5.6.1 Urban Design Impacts 106
5.6.2 Transportation's Impact on Land Use 106

REFERENCES

LIST OF TABLES

Page

Table 2-1: Socio-Economic Input Data Sources 9

Table 2-2: Land Use and Socio-Economic Data Relationships 10

Table 2-3: Special Generation Input Data Sources 15

Table 2-4: Network and Travel Cost Data Sources 17

Table 2-5: Calibration and Validation Data Sources 27

LIST OF FIGURES

Page

Figure 3-1: Four-Step Travel Demand Forecasting Process 31

Figure 3-2a: Trip Generation Techniques Cross-Classification Method 39

Figure 3-2b: Trip Generation Techniques Linear Regression Method...................... 40

Figure 3-3: Trip Production and Attraction Model Results.................................. 44

Figure 3-4: Trip Distribution Model and Impedance Tables................................ 46

Figure 3-5: Typical Travel Impedance Distribution 48

Figure 3-6: Mode Choice Model.. 55

Figure 3-7: Nested Mode Choice Model Structure.. 57

Figure 3-8: Volume-Delay Curves for Capacity Restraint.................................. 63

Figure 3-9: Maximum Desirable Deviation in Total Screenline Volume 68

Figure 3-10: Time-of-Day Distribution by Trip Purpose.................................... 70

Figure 3-11: Feedback Mechanisms to Equilibrate Impedance.............................. 72

Figure 4-1: Hydrocarbon Emissions by Type for Prototypical Trip.. 79

Figure 4-2: Expected Change in Hydrocarbon Emissions Over Time for Prototypical Trip 79

Figure 4-3: Relationship of Emission Rate to Speed... 81

Figure 4-4: Relationship of Hydrocarbon Emission Rate to Speed by Vehicle Type 81

Figure 4-5: Detailed Flow Chart for Emission Estimation Procedures 83

CHAPTER 1

INTRODUCTION

CHAPTER 1. INTRODUCTION

1.1 PROJECT OVERVIEW AND OBJECTIVES

Travel demand forecasting models have been developed and applied over the last three decades to forecast travel demand for long term planning activities such as alternatives analyses, county general plans, and corridor analyses. In recent years, these travel demand forecasting models are being proposed for use in estimating emissions, traffic operational analyses and congestion management planning, brought about by the passage of the Federal Clean Air Act Amendments (1990) and the California Clean Air Act (1988) and the Congestion Management Program (1990). Each of these uses will have different requirements for the accuracy and usefulness of the model outputs, and the validity of the input assumptions and data. These new uses for existing travel demand forecasting models has prompted the California Department of Transportation to prepare this uniform set of travel demand forecasting guidelines.

The state and federal legislative requirements for modeling, particularly California's Congestion Management Program, have resulted in a proliferation of regional or countywide models. While regional modeling used to be practiced by only a few metropolitan planning organizations (MPOs) in the state, the CMP legislation has led to the development of a countywide model by virtually every county in the state that contains an urban area. Many of the regional or countywide models in the state are reasonably sophisticated and constitute good modeling practice, but some MPOs or CMP agencies are using procedures that have not been updated since the 1960s or 1970s or are using defaults provided with the software package being used by the agency. As a result, there is considerable variation in the level of sophistication and the level of accuracy of regional models within the state. This effort to develop statewide guidelines is designed to raise the overall level of the quality of modeling within the state and to provide some consistency in the way that modeling is practiced.

The primary purpose for regional modeling of travel when it was begun in the 1960s and 1970s was to determine the need for major highway investments. This determination was most often made on the basis of projected volumes on particular roadway links and from that estimation of the number of lanes of additional capacity needed or the need for new roadway facilities. When used for this purpose, rough approximations of forecast volumes was sufficient to determine when major new widenings or new facilities were needed. In the current regulatory and legislative environment, however, significantly greater accuracy and sensitivity is necessary. With the current emphasis on meeting air quality standards within the state, a primary focus in this project has been developing guidelines to improve the forecasting of travel activity data as an input to emissions estimation as part of an overall conformity analysis for regional transportation plans and transportation improvement programs. Because of a number of other regulatory and legislative requirements, there is also secondary concern about the accuracy of models for producing inputs to level of service calculations as required by the Congestion Management

Program, the evaluation of transportation control measures as required by the federal and state Clean Air Acts, and for evaluation of alternative modes such as transit or other high occupancy vehicle modes, including carpooling and vanpooling. Within each of these areas, there is concern about inconsistencies and inaccuracies in the model systems and how they represent travel behavior. Greater accuracy is desired as a means of more efficiently planning for transportation facilities or facility management programs. Greater consistency is desired to facilitate comparison of forecast between regions or between agencies within a same region in a process of prioritizing state project funds. For this purpose, there is a desire for the establishment of more consistent methodologies for travel forecasting and for more consistent use of assumptions within the models.

1.2 SUGGESTED USE OF THE GUIDELINES

The primary purpose for this project is to document reasonable and consistent methods that should be used in the preparation of regional travel forecasts developed to yield mobile source emissions inventories. This purpose has been addressed in this project in three major steps. They are as follows:

1. Providing an overview of the state-of-the-practice in transportation modeling.
2. Describing the linkage with mobile source emission inventories, including methods for addressing transportation control measures in the modeling process.
3. Discussing future research and model improvement needs.

The first two steps have resulted in the development of guidelines for minimal acceptable practice within the state. What constitutes minimal acceptable practice is often a function of the specific use for which a model is intended. However, this project has been oriented to models as they are used to provide input to a regional emission inventory or conformity analysis. Given this general purpose, what constitutes minimal acceptable practice would only vary as a function of the complexity of travel behavior in the region and the resources of the agency maintaining the model. This might result in different standards for small, medium, and large agencies. Some of the criteria that distinguish the level of complexity of travel behavior within a region would be --

- Multimodal Travel: a significant percentage of the passenger travel in the region is by rail, bus, vanpool, or carpool and the model is used to estimate the distribution by the various modes;
- Multi-County: the model produces forecasts for multiple counties and serves as a regional model that supports subarea models;
- Population: the model is used for forecasting in a large metropolitan area with multiple employment centers;
- Congestion: the level-of-service during peak commute periods is significantly different than level-of-service in the off-peak periods and congestion influences route or mode choice; and

o Air Quality: *the region is a serious, severe, or extreme non-attainment* area.

Using these criteria, two categories of regional modeling agencies have been identified. Those that would be considered complex with respect to most or all of these criteria constitute the first group; the second group would be all other agencies maintaining models for the purpose of emission inventories or trip conformity analysis. The first group is defined to include the MPOs for the four major metropolitan areas in the state: Los Angeles - Southern California Association of Governments; San Francisco/Oakland - Metropolitan Transportation Commission; Sacramento - Sacramento Area Council of Governments; and San Diego - San Diego Association of Governments. These four agencies are expected to maintain a more advanced modeling methodology than the other agencies in the state. The guidelines developed in this project specify a minimum acceptable standard that would apply to all agencies throughout the state and a more advanced level of acceptable practice that would be expected from the four larger agencies.

The material in this report is divided into two parts. Specific guidelines are included in boxes for easy identification, but additional text is provided to support the guidelines and to provide some additional assistance in defining the current state-of-the-practice and what constitutes good practice. Given the orientation of this document, it is expected that it would have a variety of audiences. These might include executive management level officials determining whether existing modeling practice is acceptable, or technical staff evaluating their own modeling capabilities. For these audiences, the guidelines can be used for a number of purposes, including the following:

1. To insure that modeling is performed correctly;
2. To achieve a *minimum acceptable level of accuracy*;
3. To provide some standardization and through it, better understanding of the modeling being performed;
4. To *adopt universally accepted definitions and terms*;
5. To meet the requirements of specific legislation in the state; and
6. To conform with what might be established as a legal basis for acceptable practice.

Forecasting of travel behavior involves representation of numerous complex decisions and forecasts can only be expected to roughly approximate reality. The state-of-the-art in travel forecasting continues to improve as individuals pursue new methods for analytically representing the complex decisions being made. Though these guidelines are intended to provide some degree of consistency through standardization of methodology, they are not intended to stifle the creativity that will ultimately lead to improvements in the practice. The guidelines are designed to represent a minimum level of acceptable practice and as such, designed to establish a minimum level of consistency and accuracy. To provide this desired consistency without restricting creativity, the document focuses on the principles of good forecasting practice rather than specifying which methods should be used. Specific methods are frequently used as examples to illustrate concepts or as useful guidance to a modeler without advanced training.

1.3 LEGISLATIVE AND PROCEDURAL REQUIREMENTS FOR USE OF THE MODEL

The Federal Clean Air Act Amendment of 1990 and the 1988 California Clean Air Act required the Environmental Protection Agency (EPA) and the California Air Resources Board (ARB), respectively, to provide guidance in meeting the Clean Air Act requirements. These acts specifically allow modeling to be a vehicle for determining compliance with the State Implementation Plan (SIP). The Federal Clean Air Act Amendment further requires that there be a consistency in methodology between the SIP, the Regional Transportation Plan (RTP), and the Regional Transportation Improvement Program (RTIP), prepared by each region in California. Both the Federal and State Clean Air Acts allow for use of models to verify the results of planning strategies to achieve the air quality standards specified in the acts. The results of the air quality modeling are then in turn verified through the monitoring of the transportation system.

Although final EPA guidelines have not been published, draft guidelines have been submitted and reviewed. The following statement is from the draft guidelines:

> In serious, severe, and extreme ozone areas, and serious CO areas, analyses to support conformity determinations made after January 1, 1994 must utilize a network-based transportation demand model that meets the requirements contained in EPA's VMT Forecasting and Tracking Guidance. The requirements address the year of most recent validation, use of constrained equilibrium for traffic assignments to alternate paths between areas, and recycling to achieve consistency between mode choice and trip distribution and zone-to-zone travel times. In addition, in these areas, analyses must utilize and document a logical correspondence between land development and use (thereby trip origins and destinations), and each transportation system scenario. The model must incorporate speed distributions which realistically reflect actual free-flow travel speeds, as well as average speed distributions over a 24-hour period; it must not limit free-flow speeds to an established speed limit without adequate justification.

During the interim period between adoption of Federal Clean Air Act and the issuance of the formal guidelines, EPA has been reviewing the modeling work performed by state and regional agencies in support of emission reduction programs and state implementation plans, regional transportation plans and regional transportation improvement programs to determine conformity between the plans and to ensure that adequate modeling is performed. EPA has prepared a checklist of questions that have been used in reviewing State Implementation Plans, Regional Transportation Plans, Transportation Improvement Plans, and the modeling that supports them. Both the draft guidelines and the EPA checklist suggests that county and regional agencies are being subjected to increasingly greater scrutiny in the Federal Conformity Analysis.

The California Clean Air Act requires that areas which cannot attain state air quality standards by the end of 1997 ("severe") to adopt transportation control measures as necessary to meet three transportation performance standards, (1) substantially reduce the rate of increase in trips and miles traveled per trip, (2) show no net increase in vehicle emissions after 1997, and (3) achieve a commute period vehicle occupancy of 1.5 by 1999. Areas which can achieve the state standard between 1995 and 1997 ("serious") need to meet the first of these performance standards.

EPA's draft guidelines have resulted in considerable ambiguity about what constitutes minimum acceptable standards, particularly for projects that are now being reviewed for conformity but for which modeling analysis has been done in previous years. The guidelines tend to suggest best practice or state-of-the-art rather than minimum acceptable practice or state-of-the-practice. This distinction was the focus of a conference in Washington D.C. sponsored by the National Association of Regional Councils. That project by NARC will ultimately lead to a manual describing best practices or state-of-the-art but leaving unresolved what constitutes minimum acceptable standards for EPA and ARB to use in evaluating modeling done in support of SIPs, RTPs, and RTIPs. We view a central focus of this project to be a definition of what constitutes minimum acceptable standards within the travel forecasting industry, while at the same time, identifying what constitutes preferred practice and where appropriate, best available practice.

It certainly will be the case that the requirements, or guidelines, will vary depending upon the purpose for which model output is to be used. Forecasts prepared for air quality analysis will have higher standards for accuracy and the estimation of trips because the number of trips is as an important determinant of emission estimates for certain pollutants as the number of vehicle miles traveled. Modeling use in support of Congestion Management Plans will have a higher standard for volume estimates on critical links and nodes because of the need to evaluate level-of-service in connection with the CMP program. Models used for analysis of transit, HOV, ridesharing, or TCM analysis will have a higher standard for mode choice and vehicle occupancy estimation procedures because of the sensitivity of the outcome to that analysis. However, while the standards may vary depending upon the use, a regional agency may choose to achieve a single set of higher level standards because the model system will ultimately be used for all of the purposes defined above. The conformity requirements of the Federal Clean Air Act will also increase the pressure for a consistent set of modeling procedures being used within a region.

The Congestion Management Program requires consistency among modeling procedures, but is ambiguous as to the guidelines for consistency. Section 65089. (c) of the Government Code states that "The agency, (CMA), in consultation with the regional agency, cities, and the county shall develop a uniform database on traffic impacts for use in a countywide transportation computer model and shall approve transportation computer models of specific areas within the county that will be used by local jurisdictions to determine the quantitative impacts of development on the circulation system that are based on the countywide model and standardized modeling assumptions and conventions. The computer models shall be consistent with the modeling methodology adopted by the regional planning agency. The databases used in the models shall be consistent with the databases used by the regional planning agency. Where the regional agency has jurisdiction over two or more counties, the databases used by the agency shall be consistent with the databases used by the regional agency." In order to improve the effectiveness of this consistency requirement, regional transportation agencies will need a set of guidelines for modeling procedures.

1.4 OUTLINE OF THE REPORT

The Caltrans Travel Forecasting Guidelines consists of two chapters that provide guidance on travel demand modeling, one chapter on the requirements that emission inventories places on travel demand modeling, and one chapter on further research that will promote improved travel demand modeling for air quality analysis. Following the introduction, the Travel Forecasting Guidelines is organized as follows:

Chapter 2: Input Data and Assumptions

Chapter 3: Travel Demand Modeling

Chapter 4: Emission Inventory Needs

Chapter 5: Research and Recommendations

CHAPTER 2

INPUT DATA AND ASSUMPTIONS

CHAPTER 2: INPUT DATA AND ASSUMPTIONS

This chapter describes the socio-economic, network, and validation data required for the different levels of regional models and methodologies for obtaining, estimating, coding, and error checking the data.

2.1 OVERVIEW

Input data requirements vary according to the goals and objectives of the model. Analyses designed for estimating transit patronage, or the effectiveness of transportation control measures (TCMs), will require more input data than models designed for assessing local traffic patterns and flows.

Transportation analysts must also balance the desire for more refined data against budget and time limitations. A careful balancing of modeling objectives and resources is required.

The input data requirements depend on whether the objective is base year model development (model calibration or validation) or future year forecasting, although there is overlap between the two. All modeling approaches require as a minimum the number of households and employment in each zone plus a highway network. The advanced approach augments these basic data requirements with additional information on income, population, auto ownership, travel costs, and a transit network.

Acceptable Approach

An acceptable modeling approach designed to forecast daily vehicle trips requires only basic residential (household) and non-residential (employment) data. The household data should be stratified by income or auto ownership and may also be stratified by other significant trip-making variables: number of persons, structure type (single family, multi-family, etc.), density (dwelling units/acre), or workers per household. Stratification of households can be estimated from mean values and existing distribution curves. The employment data need to be stratified into retail and non-retail categories, or basic and non-basic employment.[1] All of the data must then be distributed geographically into zones for the model. Major special generators should also be included, such as colleges, airports, military bases. These models may use "land use" based information, such as acres of residential uses, acres of industrial uses, building permits, and other readily accessible information that most city/county planning departments have, as opposed to "socio-economic" data derived from demographic and economic forecasts, with appropriate comparisons to reflect the compatibility of the data.

Advanced Approach

[1] Area(e.g., acres) may be also used for the non-residential trip end estimation.

The advanced modeling approach would include (in addition to the data required for the acceptable approach) a stratification of the employment into four or more categories, generally following the Standard Industrial Classification Codes or ITE land use codes. Cost of travel data (tolls, parking costs, fares, auto operating costs, etc.) would be required for mode choice and other models. The management of an agency should determine which approach is acceptable, although this approach is generally applicable only to the state's four largest metropolitan areas: Los Angeles, San Francisco, San Diego, and Sacramento.

The recommended methods for obtaining and forecasting this data are discussed in the remaining sections of this chapter. The discussion is divided into six sections:

- o Socio-economic Data,
- o Special Trip Generators,
- o External Stations and Trips,
- o Network Data,
- o Travel Cost Data, and
- o Calibration and Validation Data.

The discussion generally follows the following format:

o	Objective:	Why are the data needed? What are they used for? How critical are they for the accuracy of the model?
o	Data Sources:	What are the best sources and methods for obtaining and/or estimating the data?
o	Forecasting Procedures:	What techniques should be used to forecast the data?
o	Error Checks:	What coding methods and error checking routines can be employed to ensure accuracy and reliability?

2.2 SOCIO-ECONOMIC DATA

Socio-economic data consist of housing and employment data. These data are supplemented with income and auto ownership data. Table 2-1 summarizes the recommended sources for the input data for models. There is often confusion about the difference between the terms *socioeconomic* and *land use* data. Table 2-2 may help clarify this relationship. Generally land use data involves areal units, such as acres or square footage. Socioeconomic data involves direct observations of social or economic characteristics, such as population, auto ownership, or employment. It is possible to go between the two types of measurements using conversion factors, as noted in Table 2-2.

2.2.1 <u>Household, Income, and Auto Ownership Information</u>

Information on the number of dwelling units, households, population, workers and household income are among the straightforward data to obtain for modeling purposes. The decennial U.S. Census provides most of this information at the census tract and block group levels. Transportation analysts must split (or aggregate) the data into analysis zones.

Objective

The number of households or dwelling units in a zone are used to estimate trip productions by each zone. This is a critical piece of information since trip attractions are normalized to trip production estimates. Household data are generally preferred to dwelling unit information, since dwelling units may be unoccupied. If dwelling units are used to estimate trips, it is important to identify the definition of dwelling unit to include or exclude vacant dwelling units.

Structure type (eg. single family detached versus multi-family), population, income, and auto availability provide supplementary information that improves the accuracy and sensitivity of the trip generation forecasts. Income and/or auto availability are critical pieces of information for the trip generation and mode split analysis.

The number of autos/vans/small trucks available for household use shows a considerable correlation with both person and vehicle trip generation of the household. It also influences mode choice, since zero-auto households are "transit or carpool passenger captive".

Table 2-1
Socio-Economic Input Data Sources

Data Type	Best Source(s)	Back-Up Source	Alternate Estimation Method
Households	Latest U.S. Census. Split Tracts as necessary.	Aerial Photos and Field Counts	Aerial Photos, building permits, utility company records
Employment	Latest Census Transportation Planning Package (CTPP). Split Census Tract data as necessary.	State Employment Office data by zip code. Split zip codes as necessary.	Derive from surveys of floor space and average employee densities. (Not recommended)
Median Income or Households stratified by Income	Latest U.S. Census	Derive stratification from median income	State Franchise Tax Board (Form 540 tax returns)
Average Population per Household or Households stratified by Persons/household	Latest U.S. Census	Derive stratification from ave. population/house (less satisfactory)	None

Note: The committee overseeing this report expressed several different views of what constituted the best sources of input data. Different circumstances may indicate different approaches. The analyst should therefore be cautioned that the above table does not represent definitive judgment in all cases. Each data source has some advantages and some disadvantages.

Table 2-2 Land Use and Socioeconomic Data Relationships			
	Basis	Residential Variables	Non-Residential Variables
Socioeconomic Data	people	households income auto ownership population dwelling unit type	employment
Conversion Factors	density	households per acre	employees per acre or employees per sq. ft.
Land Use Data	area	acres	acres or square feet

Household income or auto ownership must be included if models have a mode split/transit component, since low income and/or zero-car households are much more likely to use transit. Income or auto ownership is desirable even for highway models, since income is highly correlated with the number of trips made.

Non-Household Population is a variable infrequently included in models. This includes persons whose primary or permanent residence is outside of traditional housing units, in barracks, dormitories, nursing homes, congregate care facilities, or institutions (hospitals, prisons). The single characteristic that probably best defines this group is that eating/kitchen facilities are in common (shared). Three unrelated adults sharing a rented single-family home should be considered a "household" for purposes of trip generation analysis.

The importance of group quarters population will depend upon the number of such persons there are (they are classified in the census). In some cases, the non-household population may be treated as part of some larger special generator (like a military base or university).

Data Sources

The Census Bureau (US Department of Commerce) decennial census is the best source of information on current population and housing (including population, age, dwelling unit number/type data (see Table 2-2), by Census Tract or Block group.

The California Department of Finance also provides estimates of existing city and county population for January 1 and July 1 of every year. The California Department of Motor Vehicles can provide information on vehicle registrations by type of vehicle by county. This is useful in establishing historical vehicle ownership trends. Aerial photos may be helpful, but since the use of the structure is difficult to discern (except for single family homes), they are useful mainly for dwelling unit counts. Aggregation of the large number of photos needed to cover any reasonable size study area is also very time consuming. Local utilities are a source of new water or electric connections, by type of unit (single family, multi-family, commercial) and can be helpful in identifying growth since the last census.

Forecasting Procedures

Planners typically forecast population and household growth using one of two procedures: a "market based" approach based upon demographic and economic trends, and a "build-out" approach based upon local agency General Plans. These procedures are sometimes distinguished as "top down" and "bottom up" approaches.

The "top down" approach is preferred because it is based on national, state, and regional economic and demographic trends which are known to control regional growth. Land use plans by contrast can only allocate the growth to specific geographic locations. The ideal forecasting approach combines both approaches, identifying and resolving differences between local General Plans and economic reality.

The most important criteria in picking any approach is that it be consistent with the decennial census, in terms of the variables produced. Various survey methods that can be used to update the census are discussed later in this chapter.

- Population Forecasts: The California Department of Finance (DOF) forecasts the population of the state for five year intervals to the year 2020. Recent DOF experience indicates that the greatest source of error in predicting California's population has been in predicting net migration and births, both of which were greater than projected during the 1980's. Migration depends on state, national, and international conditions that are very difficult to forecast. Births depend on age-specific fertility rates, which also can be difficult to predict. Population growth is allocated to the counties based on current and estimated future shares of state growth. Advanced practice should include in-house cohort survival and migration models.

- Household Forecasts: The current trends in persons per household are extrapolated and modified based upon current expectations regarding household formation and family size. Local planning departments typically make forecasts of household size in their General Plans. The forecasted number of households is calculated by dividing the population forecast by the estimated number of persons per household.

- Allocation to Jurisdictions and Zones: An acceptable method of doing population forecasts, particularly for shorter term periods, is a "shift/share" type of model. A shift share model begins with the assumption that an area has typically "captured" a certain share of growth in the state/region/county. More advanced practice should allocate land uses to the TAZ's (Traffic Analysis Zones) based on factors such as availability of land suitable for particular uses, topography/slopes, zoning and growth control ordinances/restrictions, and so forth. The details of this methodology is beyond the scope of this document, however.

Usually there is relatively little dispute regarding the total regional forecasts. Some local agencies may dispute allocations at the jurisdiction level. Most of the problems occur at the zonal level where a great deal of judgement is used to decide which zones get which kind of growth. At this microscopic level, a detailed review by local agency planners is extremely valuable.

Error Checks

The recommended procedures to follow in validating socio-economic input data are as follows:
o *Check data against city/county regional control totals* o *Compare existing to forecasted data by district* o *Check densities by zone* o *Check jobs/employed residents balance (difference is net importation of workers)*

- o Check Data Against City/County/Regional Control Totals: Sum up existing and future zonal population, household, employment, and other socio-economic data by city and county and for the whole region. Check these totals against control totals for these jurisdictions obtained from Census data and independent forecasts for jurisdictions.

- o Compare Existing to Forecasted Data by District: Subtract the existing data from the forecast data at the zone or district level. This will show which zones grow (and which ones decline) in activity level, and may indicate inconsistencies in the forecasting techniques or "busts" in the keypunching. Negative growth in particular should stand out. A GIS or graphic software color display of this data by zone is especially useful for spotting errors.

- o Check Densities: Calculate population, employed resident, and employment densities (persons per acre) for each zone and display in a GIS format using colors or bar charts keyed to density. Aberrations will stick out like "sore thumbs". Look for zones that violate general trends in density.

- o Check Balance: Check ratio of employed residents to jobs at regional level (be sure to add in external residents working in the region and subtract residents working outside the region into the calculation). The ratio should be within a few percent of 1.0.

More advanced practice should consider the allocation of socio-economic data to individual traffic zones. Forecasting this information is best performed within a computer software package that can automatically track the totals and the allocations.

2.2.2 Employment Information

Employment data are one of the more difficult pieces of input data to obtain for a model. It is prone to a greater level of uncertainty than household information. The best sources are at the state level. Some analysts have attempted to use commercial floor space in-lieu of employment data but their models have been subject to a greater level of uncertainty (and consequently more difficult to calibrate) since not all floor space is occupied and occupancy densities can vary widely.

Data Sources

There no single "best" source of employment data. The modeler must trade off accuracy and reliability against the difficulty of obtaining data from the respective source. Some recommended sources for both acceptable and advanced practice are noted below.

The California Employment Development Department (EDD) have data on the existing number of jobs and employed residents, by industry sector and county. EDD also makes short-term projections of future employment (2-5 years out). More detailed data by zip code can be obtained on magnetic tape but these data are subject to "non-disclosure" requirements that may prevent presentation of data to the public at levels of detail that would allow the identification of a single employer in the data set. The 1990 Census Transportation Planning Package (CTPP) provides information on where resident workers work.

City/county building and finance departments may have information on building permits and local business employment, especially if the business license tax is based on number of employees. Data vary widely, but usually includes the work place address and type of business, and sometimes the number of employees on the premises. County Assessors can provide information based on their parcel records: unfortunately, use of these data will require much aggregation. Past experience has shown the records can contain some inaccuracies, and the land use codes used for assessment purposes have marginal value for transportation purposes.

Dun and Bradstreet (D&B), among others, can provide information on existing employment in an area. Information is typically provided at the zip code level, by firm size. It is also possible to obtain individual firm names and addresses, which could be aggregated into traffic analysis zones (TAZ's) using an address matching program. This information is proprietary and somewhat expensive, although it may be less costly than having to do field surveys or using other primary data collection techniques.

County Business Patterns (published every five years) provides estimates of employment by zip code and firm size (for private for-profit firms only). The Department of Commerce/Bureau of Economic Analysis (BEA) makes projections of future employment, by sector, for all metropolitan statistical areas (MSA's) in the United States. The current forecasts go out to the year 2040.

Forecasting Procedures

The forecasting procedures for employment are quite similar to those used for households. See the discussion for households for more information.

Error Checks

The coding and error checking procedures for employment data are identical to those discussed above for household information. Please see that discussion for more information.

2.2.3 Conformity For Sub-Area Models

These models are created to provide more detail within a specific jurisdiction and are designed to be used within that jurisdiction to address local concerns. However, these models could also be used to generate air quality and travel behavior information for use in decision-making at the regional level.

The regional transportation planning agency should discuss and determine with the local agencies the degree of conformity or consistency desired or required in terms of: input socio-economic forecasts, forecasting assumptions, and forecasting results. Agencies that are using area-based land use data should also develop socioeconomic data/forecasts using conversion factors that will allow for comparison to regional socioeconomic forecasts.

2.3 SPECIAL TRIP GENERATORS

Special trip generation input data are used to estimate the trip making characteristics of specialized land uses (special generators) internal to the region. Special trip generation input data sources are summarized in Table 2-3. Special generators are major land uses for which the standard trip generation and distribution equations are not expected to produce reliable estimates of their travel patterns. They augment information from the trip generation portion of the forecasting process.

Special generators should be used wherever trip generation cannot be adequately represented by the standard equations in the trip generation model. At a minimum, special generators should represent airports, colleges and military bases.

The best source of existing condition's data for a special generator is a cordon count of the generator (to establish trip generation) plus socioeconomic data on the generator provided by the institution itself. Where actual trip generation counts of the site (either using manual techniques or automatic counters) are not feasible, then published trip generation studies may be used, such as; Institute of Transportation Engineer's Trip Generation, Caltrans District 4 (the periodic "Progress Reports on Trip End Generation"), and the San Diego Association of Government's "Traffic Generators." Special generators may generate trip productions, trip attractions, or both.

The travel characteristics of special generators should be best forecasted based upon projections provided by the institutions themselves. In the absence of this information, the analyst may use trend line projections.

2.4 EXTERNAL STATIONS AND TRIPS

External stations are points on the boundary (or cordon line) of the region where significant amounts of travelers (usually highway traffic) enter and exit the region. Travel at an external station represents both through travel (sometimes called "X-X" trips), and other external trips (sometimes called "I-X" or "X-I" trips).

> *Acceptable practice would estimate external trips by collecting traffic counts at the external stations, while more advanced practice would include conducting origin-destination surveys conducted at the external stations.*

Table 2-3
Special Generator and External Station Input Data Sources

Data Type	Best Source(s)	Back-Up Source	Alternate Estimation Method
External Station Counts	Field Survey for model (actual counts)	Agency records	NCHRP 187
Special Generators	Actual Counts	Caltrans Progress Reports, Traffic Generators, ITE Trip Generation Manual	None

Data Sources

There are a variety of techniques for assessing base year external station travel volumes: manual and machine counts; larger (regional or Caltrans' statewide) travel models; roadside interview surveys; license plate surveys (license plate matching or postcard survey of registered owners). These input data sources are identified in Table 2-3.

Forecasting Procedures

> *Future travel to external stations should be determined by applying either growth factor techniques, or using the Statewide Travel Demand Model.*

The growth factor technique typically applies a growth factor to the existing count based on the population growth of the counties outside the model area served by that external station. Caltrans Office of Travel Forecasting can supply base and future year 2010 AADT's on State highways that cross county lines.

Error Checks

External stations are best coded as separate trip purposes. This allows the modeler to give these trips special treatment at the trip distribution stage. These data can be entered into a spreadsheet and imported into the transportation planning software package. Sources of the count data and assumptions used in the forecasts should be well documented to ensure capability of reproducing the results in future model updates.

2.5 NETWORK CODING

This section presents recommended procedures for selecting zones, coding the highway network, and coding the transit network.

2.5.1 Overview

Data Sources

The best sources of highway network and transit network data are shown in Table 2-4. Field surveys and local public works departments are the generally the best source of network information.

Forecasting Procedures

Forecasting network improvements generally consists of compiling lists of proposed, approved, and funded projects from local agencies, Caltrans, the Transportation Improvement Program (TIP), and the Regional Transportation Plan (RTP) or Transportation/Circulation Elements of Local General Plans.

2.5.2 Transportation Analysis Zones

Analysts are significantly constrained by resource availability in deciding how many zones to create in the region and what the boundaries should be for these zones. Generally, more zones means increased accuracy of the model; however, land use data is difficult to obtain for levels of detail smaller than the census tract or block group level. Zone boundaries should ideally be set to include only homogeneous land uses and to facilitate loading of traffic on the network, however; census tract boundaries pretty much dictate the feasible zone boundaries for the model.

Number of Zones

Typically 200 to 800 zones are used in urban area and single county models. Large regions may exceed 1000 zones. Rural area models might use as few as 100 zones. These are some approximate guidelines:

- o Regional models typically have zones that are aggregations of one or more census tracts. Some regions may have one zone per census tract.
- o Single county models may split the census tracts and have one to three zones within each census tract, or may use block group level data.

Whatever number of zones are used, the number of zones should be balanced to the level of detail in the coded highway network.

Table 2-4 Network and Travel Cost Data Sources			
Data Type	Best Source	Back-Up Source	Alternate Estimation Method
Highway capacities, distances, free-flow speeds, HOV facilities, Park and ride lots, Ramp metering	Field survey geometric and speed data. Use HCM to calculate capacities. Contact local office of state transportation department for HOV facility, park and ride lots, and ramp metering data.		
Transit service frequencies, distances, fares, and speeds.	Transit agency route maps and route schedules		
Cost of parking.	Survey of actual costs paid by parkers	Estimate from average parking fees charged in area discounted for employer/store subsidies	None
Perceived auto operating costs per mile.	Home Interview Survey	State or other MPO estimates	US.DOT or AAA annual estimates
Speed-flow curves by functional class	Field survey speed-flow relationships	Use 1985 HCM speed-flow relationships	BPR curve with modifications
Intersection peak period turn counts	Field surveys		
Intersection geometry and signal timing.	Field surveys and aerial photos		

If the transportation model is used for facility planning, then the network should include at least one lower level facility type than the lowest level being analyzed. Most models will have about 8 to 12 highway network links for each zone. To estimate intersection turning movements, the model needs about 3 zones for every intersection. Thus to model turning movements at 100 intersections, about 300 zones are needed. Even more zones are often needed because a less than ideal zone system must be used to conform to the Census Tract boundaries.

Too many zones can also cause rounding problems for most software packages. For models with more than 600 zones, modelers should consider using a trip generation multiplication factor of between 10 and 100 to minimize rounding problems during trip distribution and mode split.

Zone Boundaries

To the extent possible, zones should contain a single homogeneous land use (thus minimizing intra-zonal trips that are not assigned to the network). Zones should not be split by major topographical barriers to travel such as rivers, mountain ranges, canyons, freeways, etc. (since the model assumes that 100% of the zone is accessible to each of the centroid connectors by which the zone is connected to the network). Walk access to transit service should also be considered.

Practical considerations (ie. aggregation and disaggregation requirements) however dictate that traffic analysis zones nest within census tract boundaries. Census tracts may be aggregated or disaggregated as necessary, but the census tract boundaries must be preserved to facilitate working with the census data. Rules for developing zone boundaries can be found in other publications, such as the FHWA's "Calibration and Adjustment of Travel Forecasting Models" (1990).

2.5.3 Highway Networks

Basic Data (mapping)

Accurately scaled base mapping is a must for all models. The best mapping will depend upon the area covered and level of detail. US Geologic Survey (USGS) maps are often used, and are now available in digitized form for many CAD and GIS packages. Proprietary maps are often used, but the modeler should be aware that such maps contain a surprising number of errors and may not always be up to date. It may be desirable to standardize node coordinates on the California Coordinate System to make it easier to splice networks from different regions.

Centroid Connectors

Centroids are the "center of activity" of a zone. They do not represent the geographic center of the zone, unless development is uniform within the zone. Strip commercial zones are a problem with centroid location; usually drawing the zone around the strip commercial area and locating the centroid in the center of activity solves this problem, although it may still result in the modelled trips being less than the actual counts along the street, due to intrazonal trips. In large rural zones, code the centroid connector in a location representing the logical center of possible future development.

As a minimum, one can code the same speed on all connectors (typically, 15 mph). More desirable practice is to vary the speed according to the area type (e.g., CBD might be 5-10 mph, while rural areas would be 20-25 mph).The speeds on centroid connectors should represent local street system.

In a CBD, auto trips may be attracted to a zone with a *parking facility* in it rather than the zone with the attraction-end land use in it. This is particularly true if the zones are small, as suggested above, to reflect walk access to transit system. In that case, it may be desirable to consider the vehicle trip end attractions in the zone where parking is available, by re-assigning these trips after the mode choice phase.

Link Data

Link data include the inventory of the existing and future highway and transit services supplied to the area. Minimum practice is to code these types of facilities as independent functional classes:

- o centroid connectors
- o freeways
- o expressways or divided arterials
- o arterials
- o collectors

Some modelers include more detailed divisions, such as rural roads, local streets, freeway ramps (sometimes metered vs. unmetered), streets with two-way left turn lanes, and so forth. The number of classes depends upon the limitation of the software, as well as what the modeler intends to do with the information (are separate capacities or speeds to be assigned to each, for example). The degree of access control should also be taken into account when assigning link capacities.

Specific link data specifications are discussed below:

- o <u>Time/speed on link ("free" vs. congested)</u>: Most transportation software require the "free flow" speed, which represents the uncongested travel time *with traffic control devices in place* (some people think of this as the travel speed at 3 AM). In certain instances, the level of service "C" speed should be used (for example, as an input to the gravity model).

- o <u>Directionality (one or two way)</u>: Various error checking techniques are available to assure that a two-way link has not been coded as one-way, and visa versa.

- o <u>Number of travel lanes</u>: The availability of special lanes (left turn pockets, two-way left turn lanes, auxiliary lanes on freeways) increase capacity, but should generally be accounted for with either a different functional class/assignment group code, or a special user field code.

- o <u>Link capacities</u>: Link capacities are typically coded at level of service "C" (the point at which noticeable reduction in speeds begins), but in some cases LOS "E" is used. Capacities may also be adjusted, either on individual-links or network-wide, as part of the calibration process. For peak hour, use ideal <u>Highway Capacity Manual</u> saturation flows adjusted for percent green time at signals. For average daily traffic take the peak hour capacity and convert it to daily capacity assuming a set percent of daily traffic occurring during the peak hour. Daily capacities are typically 10 times peak hour but can be as high as 20 times peak hour capacity on heavily congested facilities.

- o <u>Node coordinate (XY) data</u>: Some analysts have used a generic system of coordinates, such as the state planar coordinate systems, or the universal transverse mercator (UTM) systems. USGS topographical quads usually have the former in black, and the latter in blue. Typically each coordinate (X or Y) requires five or six digits; the modeler should assure himself that his software can accommodate coordinates of this size before embarking upon coding.

- o <u>User Fields</u>: Most software also allows coding of "user" fields for a link, which can be used creatively for a number of purposes. These include specification of the city or county where the link is located; the air quality grid cell the link belongs to; whether the link is part of the (urban) county's Congestion Management Program network; the federal-aid status of the link, and so forth.

Intersection Turn Penalties and Prohibitors

Intersection turn penalties are not really necessary to get good assignments except in a fine grid network. Turn prohibitors (infinite penalties) however may be needed to prevent impossible movements (coding one way links at an intersection is an alternative to using turn prohibitors). Many software packages do not fully implement turn prohibitors. Some minimum path algorithms get confused by turn prohibitors. As a minimum, turn prohibitors should be used in any model where particular movements are not possible due to physical characteristics of the road network, or regulations. Time (delay) penalties are sometimes coded in more advanced models, and models where the size of the area and importance of the turn movements output make these delays relatively important. Most software permit at least two approaches to coding turn penalties.

Special Links and Issues (e.g., HOV, ramp metering)

- o Freeways and Freeway/Freeway Interchanges: As a minimum, these facilities should be coded as one way links with ramps as nodes. This practice tends to reduce the mistakes made in coding prohibited turns at interchanges and other locations, and makes the freeways stand out better on plots. Expressways are sometimes coded as a pair of one-way links, as well.

- o Freeway Interchanges with Surface Streets: Practice varies in this area, with the minimum being to code a freeway interchange as a set of two nodes. If this is done, the movements to/from the freeway from the surface street should probably be penalized (see above). Desirable practice is to code all important features of the interchange: entrance and exit ramps, collector/distributor roads, and so forth. If ramps are explicitly coded, the modeler should be careful that the distance and time on the ramps is correctly specified. Use of automatic features within the model to calculate distance based on coordinates should not be used for these facilities; interchanges are often "exploded" (made larger) to make them more legible on plots and computer displays, and so these features will not be truly to scale. This is particularly true where loop ramps are used, although the loop configuration need not be explicitly coded.

- o High Occupancy Vehicle facilities: Most transportation planning software available today allows coding of HOV facilities as a special type of link usable only by HOV trips (of course, a trip OD matrix of such trips is also required). The modeler should refer to the specific coding requirements in his software documentation.

- o Ramp Metering Penalties: This is an area where practice is still evolving. As a minimum, some agencies have coded a fixed penalty associated with entrance ramps of one to three minutes, to represent the average delay during the peak hour (ramp meter delays probably should not be included in ADT models). However, it has been noted that this approach may create oscillations and instabilities[1] since the delay penalty is flow dependent. A desirable approach might be to code the metered ramp as a special facility with separate volume/delay curve. The "capacity" of the ramp would have to be adjusted to reflect the average ramp metering rate over the peak period. This assumes that the ramp metering rate is fixed, which is probably not an unreasonable assumption.

---

[1] Increasing the ramp penalty will divert trips to other routes, thereby reducing demand and thus the ramp delay itself. This feedback effect may be difficult to equilibrate in practice.

Error Checks

All networks contain errors; given that literally thousands of pieces of information are included even in small networks, this is not surprising. What is surprising is that even well-checked networks can contain a surprising number of errors, and that modelers often do not make use of simple error-checking features available to them.

The modeler should spend as much time as possible in checking the networks and other input data prior to the calibration phase.[1]

The modeler should use these techniques to check his network:

- o Range checking: Check for valid ranges of input values
- o Visually inspect the network
- o Use colors to plot network attributes
- o Multiple review: have more than one person review the input data
- o Build trees/shortest paths from selected (key) zones
- o Produce and check a table of shortest travel times between zones.

2.5.4 Advanced Practice: Transit Networks[2]

Some guidelines for important transit network inputs include:

- o Transfer Links: Walking links between transit stops with a distance and walking speed (no capacity) should be coded. These are typically a maximum of one-quarter mile long with average walk speed of 2 to 3 miles per hour. Transfer time is usually weighted with a factor between 1.5 and 3, compared to in-vehicle travel time.

- o Walk Access Links: Walking links between a zone centroid and a transit stop of a given distance and walking speed (no capacity). These should be no more than half a mile long with a typical maximum speed of 2 to 3 miles per hour). Transit passengers are normally not allowed to use walk access links to walk through a zone centroid from one transit stop to another stop. Walk access links represent the primary way transit trips get to or from the transit network. They are very important because they define area that is transit accessible (unlike the highway network, many areas within the region are not within a reasonable walk of a transit line). Most networks use a rule of connecting any centroids to the network when the walk distance to a stop or station is less than .25-0.5 miles. Desirable practice is to define what percent of zone (i.e., trips) is transit accessible (e.g., 75% of the trip ends are transit accessible). This requires additional effort, but it may be possible to

[1] If the results are not checked until after calibration, it is possible that multiple errors may tend to cancel each other. This could result in satisfactory calibration, but unsatisfactory forecasts.

[2] An excellent reference on this topic has been produced by UMTA: "Procedures and Technical Methods for Transit Project Planning," Review Draft, September 1986, Part II, Chapters 5 and 6.

automate this process in the future (e.g., SANDAG is working a process using a GIS package to determine the percentage of households that are walk accessible to transit in a zone). The key is to provide small zones around areas that are transit (walk) accessible. Walk time is usually coded with a weight between 2 and 3. The weights are usually determined as part of the calibration of the mode choice model to survey data.

Walking speed is typically coded at 3 mph, but the modeler should consider barriers (topography, drainage) and steep grades as inhibitors of pedestrian access.

- o <u>Auto Access Links</u>: Auto links between a zone centroid and a transit stop of a given distance and speed (no capacity). Transit passengers are allowed to use this link in one direction (from zone to transit stop), but not in the reverse direction. For this reason, these auto access links cannot typically be used to represent the use of taxis at the destination end of a transit trip. Drive access to transit plays an important role primarily to express transit services (bus or rail) going to downtown. Auto access links should be coded only at the production end of the trip, since few people keep a car at the attraction-end of their trip (they cannot drive from attraction-end station). Some software allows this to be done in path building. In software without this feature, the directionality of the drive access link can be made one-way (*toward* the transit route in the AM peak, or *away* from transit in the PM peak).

  Auto connectors are typically coded at 15-25 mph. Since tripmakers may perceive this as out-of-vehicle (excess) time, it may be appropriate to weight this time by a factor of between 1.5 to 3 compared to in-vehicle (line haul) travel time. Usually a stiff transfer penalty is added to avoid over-estimation of trips. The penalty represents the physical time needed to transfer, as well as schedule "padding" that the trip maker adds to make sure he is at the stop on time. Some models have had to use as much as 100 minutes of in-vehicle travel time to calibrate the model, but more reasonable values are probably in the range of 10-15 minutes.

  The true catchment area for park-and-ride difficult to determine; user surveys should be used if possible to determine this. Typical practice is to link only those areas outside the walk area, and no more than 3-5 miles away; end of line stations may have larger catchment areas. It is probably desirable to restrict drive access to express bus and rail services, unless local surveys indicate otherwise. This can be done with mode-to-mode transfer prohibitors available in most software.

Basic Data

Good scaled base mapping is critical as with highway network, and even more important in downtown areas, because the density of transit routes is very high. The modeler should also obtain transit schedules and route maps for all services to be included. Minor services (paratransit, dial-a-ride, small city transit operations, club/subscription buses, airport services) are generally excluded.

Both daily and peak transit networks are used by different agencies. However, the preferred approach is to develop a peak network, since transit services often vary considerably by time of day, and it is difficult to represent "average daily" transit supply conditions. The volumes obtained from the peak hour network can be factored to daily using relationships specific to the transit operator and type of service being provided (express or local). Future transit service plans are typically developed from the region's RTP, from Short Range Transit Plans, and long range studies transit operators have done.

Headways

Typically, only transit services that have at least two trips during peak period are included in the transit network. If headways are irregular, the most common practice is to use the mean headway. When headways exceed 10-15 minutes, passengers usually consult schedules, so the true waiting time may be less than headway suggests.

The "cap" should be determined by the calibration process; it is usually in the range of 15 to 20 minutes. The modeler should be forewarned, however, that any changes in headway outside the cap (say, a reduction in headway from 60 to 30 minutes) will not show an increase in mode share. SCAG overcomes this problem by discounting the wait time for headways in excess of 20 minutes:

$$\text{Average Wait} = 10 \text{ minutes} + 0.2 * (\text{headway} - 20 \text{ minutes})$$

The theory is that for long headways travellers will schedule their arrival at the station so that all of the waiting time will not be spent at the station.

Transfer Coding

Transfers should be prohibited for certain modal combinations (e.g., drive-to-local bus). A matrix of penalties can also be added for certain types of transfers (such as drive access).

Special walk access links may be coded between transit stops/stations that are not proximate to each other, but where transfers are known to occur. Transfer wait time is usually considered to be one-half the headway of the transit route transferred to, but if timed-transfers are present, the transfer wait time can probably be capped at between five and ten minutes. No less amount of time should be used, since in most cases, the physical change of vehicle, as well as scheduling requirements, require that timed-transfers be this long.

Error Checks

Most software can now plot and/or display transit networks. The same error checking procedures used in highway network checking (noted above) should be used to check the transit network, such as zone to zone skims (both in-vehicle, as well as with waiting times added).

Some cautions:

- o Mode split is very sensitive to how the auto access links are coded. Use the same coding convention (eg. no auto access links for a zone that has walk links, no auto access links in excess of 6 miles, etc.). Once the coding convention has been established and the model calibrated, do not change the convention or the results will biased.
- o Be careful coding an auto access link in parallel to a walk link. The model will always chose the auto link, since it is faster. Then since the auto link has been selected, the model will not allow transit trips to travel in the reverse direction to access the zone!
- o Be careful about coding too many auto access links. In theory a person can drive to any transit station in the region, but since the auto is often faster than transit, the model will always choose the longest auto access link in the direction of travel to the destination.
- o Some (and perhaps many) software packages have a great deal of trouble accurately estimating average headways for "skip stop" services. Check carefully the model's estimated average headways for all the stations where some transit lines skip stops. You may need to over-ride the calculation.

2.6 TRAVEL COST INFORMATION

All costs should be expressed in a common (base) year value. The easiest way of dealing with inflation is to assume it applies equally to income and to costs. Then one need consider only those factors that might cause certain costs to increase faster than inflation.

2.6.1 Auto Operating Costs

There are few objective standards for determining auto operating costs. As a minimum, fuel costs alone (about six cents per mile in 1992) should be used. Most models use larger values (8 to 15 cents per mile); whatever value is chosen should be obtained from calibrating the mode choice model to a local travel demand (usually household travel survey) database.

The California Energy Commission (CEC) and federal Argonne National Laboratory can provide information on projected future energy prices.

2.6.2. Parking Costs

The appropriate zonal value for parking cost should also be a result of the mode choice model calibration process. Some travel demand models consider the parking cost only for those who pay for parking (e.g. the "posted parking rates on lates) A valid option is to consider average parking cost including those who park free; that way reduction or elimination of free parking (by the free market, or public policy) can be tested directly. Parking duration (typically eight hours for work trips, and one to two hours for non-work trips) should be used to convert per-hour costs into per person trip costs.

Forecasting future parking charges should be done in one of two basic ways. The minimum technique would assume that the "real" (i.e., inflation adjusted) cost remains the same in the future, or else a modest increase over inflation occurs. A better technique involves projecting parking cost as a function of employment density in CBD, or else would consider ratio of parking supply vs. demand in a specific area.

This technique would be most applicable in areas that expect to grow or densify significantly in the future.

2.6.3 Transit Fares

Future transit fares are probably best developed in discussion with transit operators, who often operate under legislative constraints in California of maintaining minimum fare box recovery percentages.

In the absence of compelling evidence to the contrary, it is probably best to assume that the existing (real) fares will remain constant in the future (equivalent to assuming that fares increase at the same rate as other prices in the economy).

Most models use the adult cash fare. It may be desirable to make exceptions where evidence suggests otherwise. For example, if a large number of commuters use monthly passes that are heavily discounted, it may be better to use that fare for home based work trips. Appropriate transfer fares (from one operator to another, or between modes) should also be included. Transit agency staff should be consulted regarding their fare increase policies.

2.6.4 Tolls

Only the three largest metro areas in state have toll facilities, although others are considering them. As a minimum practice, the analyst should convert the toll cost (e.g., $1) into time cost (say, at $6/hour), and add to the delay on link; then include in trip distribution, mode choice, and trip assignment models. Discounted tolls (using toll ticket books) might be considered if the discount is significant, and a significant number of drivers use them. The discounted value might be applied only to home-based-work trips, and could be based on the weighted average of auto toll paid. Certain software packages allow the addition of a "cost" variable to a link, which can be used to create a "user cost" network.

2.7 CALIBRATION AND VALIDATION DATA

Calibration data is used to determine the parameters and constants of the model travel demand equations. Validation data is used to determine the accuracy of the model traffic and transit patronage estimates, i.e., how well does the model perform on a known data set? Calibration and validation must utilize different data sources. Calibration data is vital to ensure the accuracy of individual equations and parameters used in the model. Validation data is vital to test the overall validity of the model's forecasts.

The best source of model estimation and calibration data is a local household travel survey that is less than ten years old. The 1990 Census Transportation Planning Package (CTPP) is the next best source of travel behavior data (however it gives information only on commuter travel[1]). The greatest strength of the CTPP is the small-scale geography to which information is coded: if a public agency provides the Census Bureau with a correspondence table between its TAZ system and census block groups or tracts, the Census Bureau will tabulate all of the transportation related questions by TAZ. Furthermore, the Bureau can produce an origin-destination matrix of "commuters" (i.e., home and work locations). This O-D matrix must, of course, be factored to produce actual trips, since not every person makes a trip to his work place each day.[2] Table 2-5 shows the data needed to develop and calibrate travel models and the best sources for this data.

[1]Multi-purpose trips (such as home-daycare center-work) are not explicitly dealt with in the census.

[2]Further information can be found in a forthcoming report to be published by ITE, "1990 Census and Transportation Planning," Report of Committee 6Y-48. Also see Transportation Research Record #981: "Uses of Census Data for Transportation Analysis," pp. 59-70.

Table 2-5

Calibration and Validation Data Sources

Data Type	Best Source	Back-Up Source	Alternate Estimation Method
Travel Demand Data			
Vehicle trip generation rates and peaking	Household travel survey	NCHRP 187 or other area surveys	ITE rates
Time and cost elasticities for mode choice.	Household survey and logit model calibration	Elasticities from other areas	NCHRP 187
Walk and auto access links.	Local coding conventions	UMTA/FTA Draft Guidelines	None
Trip length distribution	Household travel survey	U.S. Census CTPP and/or other areas	NCHRP 187 friction factor curves
Validation Data			
Daily and peak period traffic counts	7-day counts conducted specifically for model	24 hour counts obtained from agency records	None
Home interview survey	Home interview survey every 10 years	surveys elsewhere	None
Seasonal, and day of week adjustment factors	Historic data from permanent count stations	Data from other areas	HCM Manual
Vehicle occupancy	Field surveys	NCHRP 187 or other areas (not recommended)	None
Daily/peak transit boardings	Field counts for model	Transit operator records/on-board survey	None
Peak period turning movement counts	2-hr AM and PM counts for model	historic data from agency records	None

2.7.1 Traffic Counts

Counts should be for the same year as the year for which land use data have been compiled. Count locations should also be tied to the cordon line or screenlines used when calibrating the model.

Caltrans Traffic Volumes (annual publication) should be used with caution, since these counts actually represent AADT's, and are based on "profiles" of a route updated with control station counts. The local Caltrans district office may have updated other traffic counts that are not included in the Traffic Volumes report.

Screenlines should preferably bisect the study area along major physical barriers so that all real world streets that cross screenline are also in your model network. Avoid splitting zones with screenline.

Multi-day counts are best and should be geared to the season in which model is calibrated for. When calibrating a peak model, counts should all be from a consistent peak period (e.g., 4:30-5:30PM P.M.). It is desirable to have *directional* volumes for peak calibration. The count locations should be distributed throughout the study area, and used to create screenlines/cordon lines.

2.7.2 Highway Travel Speeds/ Travel Times

Travel speeds are used in coding the model. Motorists typically will travel faster than the posted speed (on average) under free-flow speeds (LOS "A"). Pneumatic traffic counters can also provide speeds. Some Caltrans districts operate tachograph-equipped trucks to perform this function regularly on freeways, and sometimes other state facilities. Floating car runs can provide a useful source of information on not only free-flow, but also congested, speeds; the model output speeds can be used as a comparison with the "loaded" (post-assignment) speeds in the calibrated model.[1]

Use of posted speeds is acceptable, but they do not always represent a good reflection of the free-flow speeds along a road; advanced practice should include "floating car" runs to check both free and congested (loaded) speeds.

2.7.3 Origin-Destination and Trip Length Information

Primary sources of information include the decennial census (for Journey-to-Work information) and the statewide travel survey (conducted in spring 1991).

---

[1] More information on floating car and other traffic data collection techniques can be found in ITE's publication, Manual of Traffic Engineering Studies, 5th edition.

Available sources of data should be supplemented with the agency's own household travel surveys at ten year intervals and possibly with roadside interview or license plate surveys at selected locations.

The biggest problem is that it is costly to collect, so it cannot be updated frequently. Small scale surveys (involving several hundred, up to a few thousand households) can be useful in calibrating the model coefficients in gravity and mode choice models. Larger surveys are needed to establish valid origin-destination patterns, particularly if the analyst wants to disaggregate this information by time of day, mode, income, or other travel-related characteristics.

2.7.4 Vehicle Occupancy

This data is usually collected for peak periods only at screen- or cut-lines, although it can be included in household travel surveys for all trip purposes and time periods. If direct observation of this information is made by surveyors, the key points in the highway network should be selected, such as external stations, cut line locations; cordons around business districts; and on freeways.

2.7.5 Local Trip Generation Surveys

Local trip generation studies can provide area-specific data on trip-making characteristics. These are usually done only for special generators, and in central business districts. ITE rates may vary in downtown areas from local data as they are based on suburban land uses, and most downtowns have a large number of trips made by parking and then walking from one activity to the next. If demographic characteristics in an area are much different than the average (e.g., family size/composition), it may be worthwhile to do local trip generation studies. Trip generation rates are sometimes adjusted as part of the calibration process. In most cases, it has been found that the "site" trip generation rate (e.g., the ITE rate for single family homes is 10.1 vehicle trip-ends/day) tends to overestimate the travel in a regional model. Typically ITE rates are from East Coast middle-income suburban areas with relatively low levels of transit service or walk mode share.

CHAPTER 3

TRAVEL DEMAND MODELING

CHAPTER 3: TRAVEL DEMAND MODELING

This chapter describes the four-step modeling process and methodologies for specifying, calibrating and validating travel demand models. The chapter also discusses time-of-day distributions, forecasts, feedback mechanisms, special model applications, regional and subregional modeling relationships and model documentation.

3.1 FOUR-STEP DEMAND MODELING OVERVIEW

Travel demand modeling, as it is most commonly practiced in California, is often referred to as the "four-step process." The four steps, as illustrated in Figure 3-1, are trip generation, trip distribution, mode choice, and trip assignment. This chapter provides guidelines for acceptable and advanced modeling practice for each of the steps within the four-step process.

As indicated in Chapter 1, guidelines have been developed for two different levels of modeling: a minimum acceptable level of practice for small and medium sized regions and a more advanced level of practice that is recommended for large regions. As indicated in Chapter 1, the differentiation between large regions and other regions is based on a combination of population and density of the region, complexity of the transportation system, number and location of activity centers, degree of congestion, and degree of air pollution. Whenever possible, it is also desirable for the models for small and medium sized regions to also meet the guidelines for advanced models. However, time, staff, and budget resources often constrain the capabilities of small and medium size regions and achieving the advanced level of practice is not always feasible.

There is substantial experience with the four-step modeling process in California. It has been in use for roughly 25 years. Most of the significant development in the four-step process occurred during the first ten years of that period. Most existing models in the state are based on a model structure and specifications that are 15 to 20 years old. The most significant advancements in the past ten years have been in transferring regional models from mainframe computer software to software that can be run on micro and minicomputer systems. With this transition has come some simplification of the model systems and some enhancement to improve the sensitivity, flexibility, or accuracy of the models.

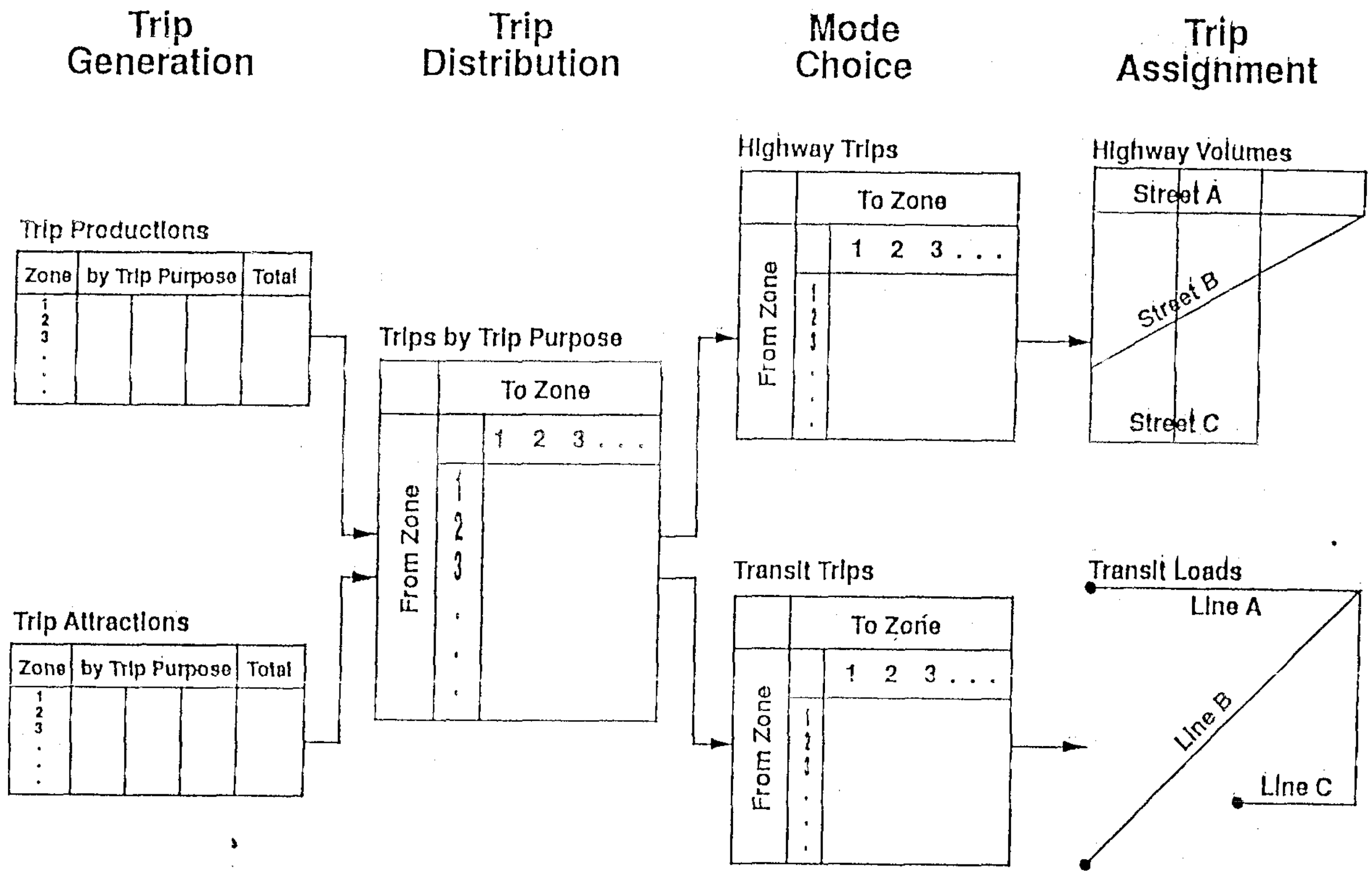


Figure 3-1
Four Step Travel Demand Forecasting Process

This chapter defines the criteria that transportation models should meet if they are to provide a sound basis for travel demand forecasting. Each model should rely on sound behavioral theory of how individuals or households make travel choices. The structure of choice sequences and the variables used in each model of choices should reflect a logical process of decision-making and the behavioral theory analyzing that process should provide a basis for judging the reasonableness of model estimation results. The models, through their input variables, should be sensitive to relevant influences. The importance of this sensitivity is necessary to capture travel behavior and to evaluate alternatives based on changes in policy or exogenous variables. If the models are not sensitive to relevant influences, then they are not useful for analyzing alternatives based on these influences, regardless of the precision with which they match base year ground counts. Finally, the models should be unbiased. Models are often calibrated to reproduce observed traffic counts or travel behavior, but without regard to behavioral theory or econometric principles. Bias in the model, due to improper or incomplete model specification, inaccurately measured input data, or multi-colinearity in input variables can result in highly inaccurate forecasts for future years. These criteria for developing and applying travel demand forecasting models are specifically designed to address the predictive capabilities of the models. If they do not capture travel behavior and remain biased, then they are not useful predictors of future travel demand.

In this Chapter, each of the four steps in the demand modeling process is described with a set of guidelines designed to meet the criteria established. Specific state-of-the-practice methods for developing models in accordance with the guidelines are also provided. The coverage of each of the four steps is provided in four parts: a description of the objective of the step, methods for specifications of the modeling procedures, methods for calibrating the procedures and methods for validating the procedures.

Specification of the models is the process of defining the model structure and the econometric methods for estimating the model and selecting the variables for inclusion in the model. Model specification also involves defining the terms relevant to each step.

Calibration is defined as the process of estimation of the parameters of the model from baseline travel data. For trip generation, the calibration process results in trip rates or equations for trip productions and attractions. For trip distribution, calibration is the estimation of the factors affecting the propensity to travel. For mode choice, calibration produces the coefficients and constants in the utility equation of each completing mode. In trip assignment, calibration results in the estimation of the parameters in the volume-delay equations.

Validation of the four-step model is the process of determining the relative accuracy and sensitivity of the model as a forecasting tool. This usually involves the application of the modeling processing using aggregate data sources, representing a current or previous year, and the comparison of the results to actual data collected in the field. Validation data sources should be different than those used in calibration but validation can also include application of the model with the calibration data but stratified by socioeconomic characteristics or geographic subdivision. This provides a test of the sensitivity of the model to variation in input data. Validation may also include checks on the reasonableness of model parameters. This can be done by comparison of model results with results from other models in the state or to reported state or national trends. Validation using actual data sources is often limited to verify the entire four-step process, after trip assignment, but each of the other three steps in the process should be validated for consistency and/or reasonableness. Each step in the four-step process incorporates the results from the previous steps and should be validated separately to reduce the compounding of errors.

3.2 TRIP GENERATION

3.2.1 Objective

Trip generation models provide the estimates of the number of trips (by purpose) produced by or attracted to a traffic analysis zone as a function of the demographic, socioeconomic, locational, and land use characteristics of the zone. Trip generation models have three parts: trip production models, trip attraction models and the normalizing or scaling process that converts the total trips generated into trip productions and attractions. Trip productions are defined as the number of trips produced in a traffic analysis zone; trip attractions are the number of trips attracted to a traffic analysis zone. Trip production models estimate trips produced in a zone, trip attraction models estimate the trips attracted to a zone and the scaling process ensures that, for each trip purpose, the number of trips attracted within the total modeling domain equals the number of trips produced.

The distinction between trip productions and attractions and trip origins and destinations can be described with an example: If a traveler makes a round trip from home to work, the trip generation model will estimate two home-based-work trip productions from the home zone attracted to the work zone, and the trip balancing process (to convert trip productions/attractions to origins/destinations) converts these two trips into one home-based-work trip from the origin (home zone) to the destination (work zone), and one home-based-work trip from the origin (work zone) to the destination (home zone).

In California, trip generation models are divided into five areas: home-based trip productions, home-based trip attractions, non-home-based trip productions and attractions, internal/external and external-internal trips productions and attractions and external (through) trips. The areas are distinguished by the measures, or variables, used to estimate trips. Non-home-based trips are generated from residential variables and converted to trip productions through a re-allocation process that shifts the production zone from the residential areas to the non-residential areas, in keeping with the nature of non-home-based trips. External trips are often estimated outside of the trip generation model, based on trip-making characteristics outside the study area or region.

Trip generation models can be designed to produce estimates of either person trips or vehicle trips, depending on the derivation of the trip rates or equations. A model that produces estimates of vehicle trips, in the trip generation step of the process, precludes the application of a separate mode choice model in the third step of the process because the mode has been pre-determined to be auto (or vehicle) for all of the trips generated. Such models have no sensitivity to policies or programs that would influence mode choice or auto occupancy severely limiting their usefulness for transportation planning in the current environment.

Trip generation models should estimate person-trip productions and attractions for each traffic analysis zone.

3.2.2 Modeling Specifications

Trip generation models determine the total number of trips or the demand for travel of each traffic analysis zone in the region. The results of the trip generation models are used in conjunction with the other three modeling steps to estimate travel demand for each highway and transit route segment. The results of the trip generation model are also used to estimate trip-related emissions (starts and parks) for air quality analysis.

Trip generation models should be based on an econometric relationship that estimates person trip productions and attractions on the basis of trip-making behavior of the individual, land uses, and socioeconomic characteristics.

The econometric relationship of a trip generation model defines the frequency and distribution of travel as a function of the activities and land uses in a traffic analysis zone. This model assumes that trip making and activity can be related by trip purpose. Trip purposes are classified as home-based or non-home-based trips. The model also assumes that the intensity of travel can be estimated independent of the transportation system characteristics. This assumption has been questioned and will be addressed further in Chapter 5. Finally, the model assumes that the relationships between trip making and activity will remain stable over time. The remainder of the discussion on trip generation model specifications focusses on definition of trip purpose, residential and nonresidential trip generation models, and special generator trips.

Trip Purposes

Trip generation models include individual specifications for trip productions and attractions by trip purpose. The decision to include more trip purposes should be weighed against the increased complexity and effort involved in estimating travel behavior for each purpose. Trips are defined as internal, if both ends of the trip are within the study area, and external, if both ends of the trip are outside of the study area. Trips with one end of the trip in the study area and one end outside the study area are internal-external or external-internal trips. Most models stratify trips by purpose only for internal trips.

> *Travel demand forecasting models should provide estimates of trips for at least three internal trip purposes (home-based work, home-based non-work and non-home-based), and should differentiate internal-external, external-internal, and external-external (through) trips. Advanced models should estimate trips for at least five internal trip purposes, in addition to the other externally-related trip types.*

The trip purposes stratify travel behavior into activities such as work, school or shopping. The model generates or attracts trips by purpose to a particular zone and provides sensitivity in the model to evaluate trip-making behavior. If a regional agency proposes to estimate trips for three internal trip purposes, these purposes are most often defined as:

- o home-based work;
- o home-based non-work, and
- o non-home-based.

If a regional agency proposes to estimate trips for five or more internal trip proposed, then the trip purposes to consider include:

- o home-based work (or home-to-work)
- o home-based shop (or home-to-shop)
- o home-based social/recreational
- o home-based school
- o home-based other (home-to-other)
- o non-home-based (or other-to-other and/or other-to-work)
- o visitor (total-based trips)

There are two types of trips that introduce additional complexity into specifications of trip purpose: linked trips and chained trips. Linked trips are those trips that serve a passenger, such as taking a student to school, or that require multiple modes, such as driving to a transit station and completing the trip on transit.

Linked trips should be included in the travel demand model as a single trip.

Chained trips are trips with more than one purpose, such as stopping at the dry cleaners on the way to work. Chained trips are represented in the model as two un-related trips, each with a single destination and single purpose. Accounting for multiple-purpose trips, or trip-chaining, is addressed in Chapter 5.

It is important to recognize the definition of chained trips in the survey data available for use in developing the model. The Census Journey-to-Work data defines the single or multi-purpose trip to the work place as one trip from home to work. This definition is not compatible with most surveys taken in California, including the Caltrans Statewide O-D Survey, which defines any multi-purpose trip as two (or more) individual trips.

Home-Based Trip Production Models

Trip generation models are defined by the travel behavior associated with home-based trips and estimate trips based on a measure of resident population. The most commonly used variable in these models is the number of households or occupied dwelling units in a traffic analysis zone, although residential population can be used in combination with the number of households or dwelling units. Home-based trip production models should also include socioeconomic characteristics of the resident population to refine trip rates. The most common socioeconomic characteristics used in home-based trip production models are income and auto ownership. Additional socioeconomic characteristics that may be used include household size, dwelling unit type (single family or multi-family), density (dwelling units per acre) or workers per household.

Home-based trip productions should be based on a measure of residential population and should be stratified by income or auto ownership and may also include other socioeconomic characteristics of the residential population.

Home-Based Trip Attraction Models

The trip generation models produce estimates of home-based trip attractions based on the land use or socioeconomic data of a traffic analysis zone. The home-based trip attractions should be based on an estimate of the intensity of the non-residential uses (number of employees or floor area) and the nature of the use (the type of industry) and possibly a measure of the population. The stratification of non-residential uses should include at a minimum, retail and non-retail land uses. Further stratification of non-residential land uses could easily be justified by the range of trip attraction rates developed for these land uses in ITE's Trip Generation (ITE, 5th Edition, 1991), but needs to be weighed against the difficulty of estimating and projecting these data for application of the model.[1] Four or more categories of non-residential data are recommended for advanced models to capture the variations in travel behavior affected by different types of land uses. Some typical categories for non-residential land uses include agriculture, industry, commerce, office, public buildings, transportation and utilities, and/or education and health. It is important to recognize the difference between land use (or socioeconomic) categories and Standard Industrial Classifications (SIC). Land use data describe the type of activity and SIC codes describe the type of industry. An example is the headquarters of a mining corporation, which has a SIC code for mining and an office land use.

Home-based trip attraction models should be based on non-residential land uses stratified by at least two categories of land use or socioeconomic data. Advanced models should stratify non-residential data by at least four categories of land use or socioeconomic data.

Non-Home-Based Models

Non-home-based trip productions and attractions are related to an estimate of the residential and non-residential land uses in an analysis zone. These trips will include visitor trips, trips by workers from work to shop, non-work trips by residents for which neither end of the trip is home, and truck trips. The non-home-based trip purpose often provides less accurate estimates of trips than the home-based purposes because of higher uncertainty in the estimates of non-residential land uses and the lack of data collected in most travel surveys for this purpose. Commercial (including truck or freight) travel is particularly difficult to explain in the absence of a survey directed at commercial travel. Non-home-based travel should incorporate a measure of residential population as well as non-residential land uses stratified by industry type.

Non-home-based trip productions and attractions should be based on a measure of residential and non-residential land use or socioeconomic data, stratified by the nature of use or the socioeconomic characteristics.

State-of-the-Practice Methods

Two commonly used techniques for estimating internal trip productions and attractions are the cross-classification method and the linear regression method. The cross-classification method is simple to calibrate and apply and requires fewer assumptions about underlying distributions among the zones than the regression method. The cross-classification method requires a reasonable number of observations in each of the cross-classification cells, and these data are generally more readily available for home-based trip production models than for the other trip

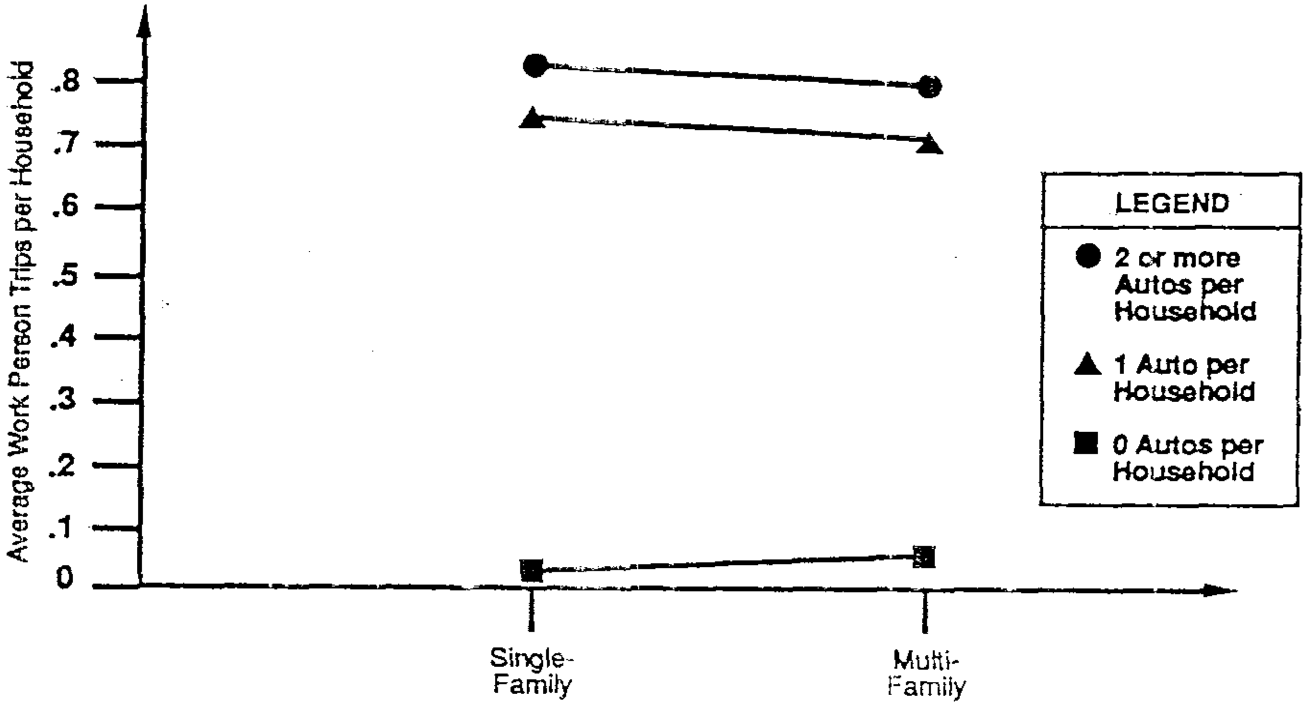
[1] The ITE Trip Generation report should not be used to estimate trip rates for home-based trip attraction models. It is presented here as a tool for identifying appropriate stratifications of non-residential land uses. It can also be used to estimate special generators.

generation models. Regression analysis can have problems resulting from highly correlated trip-making characteristics. These correlated variables can produce illogical coefficients and bias constants that are inappropriate at the traffic analysis zone level. This has further repercussions for applying the regression analysis to a focussed model with large variations in zone size or for transferring the model to an area with different zone sizes.

The two methods are demonstrated in Figure 3-2a and 3-2b: the cross-classification example estimates home-based-work trip productions from trip rates by auto ownership and type of dwelling unit and the linear regression example estimates home-based work attractions from total employment.

> Linear regression or distribution curves can also be used to stratify the households or dwelling units into auto ownership or income categories. An example of a linear regression equation to stratify households into auto ownership categories is:

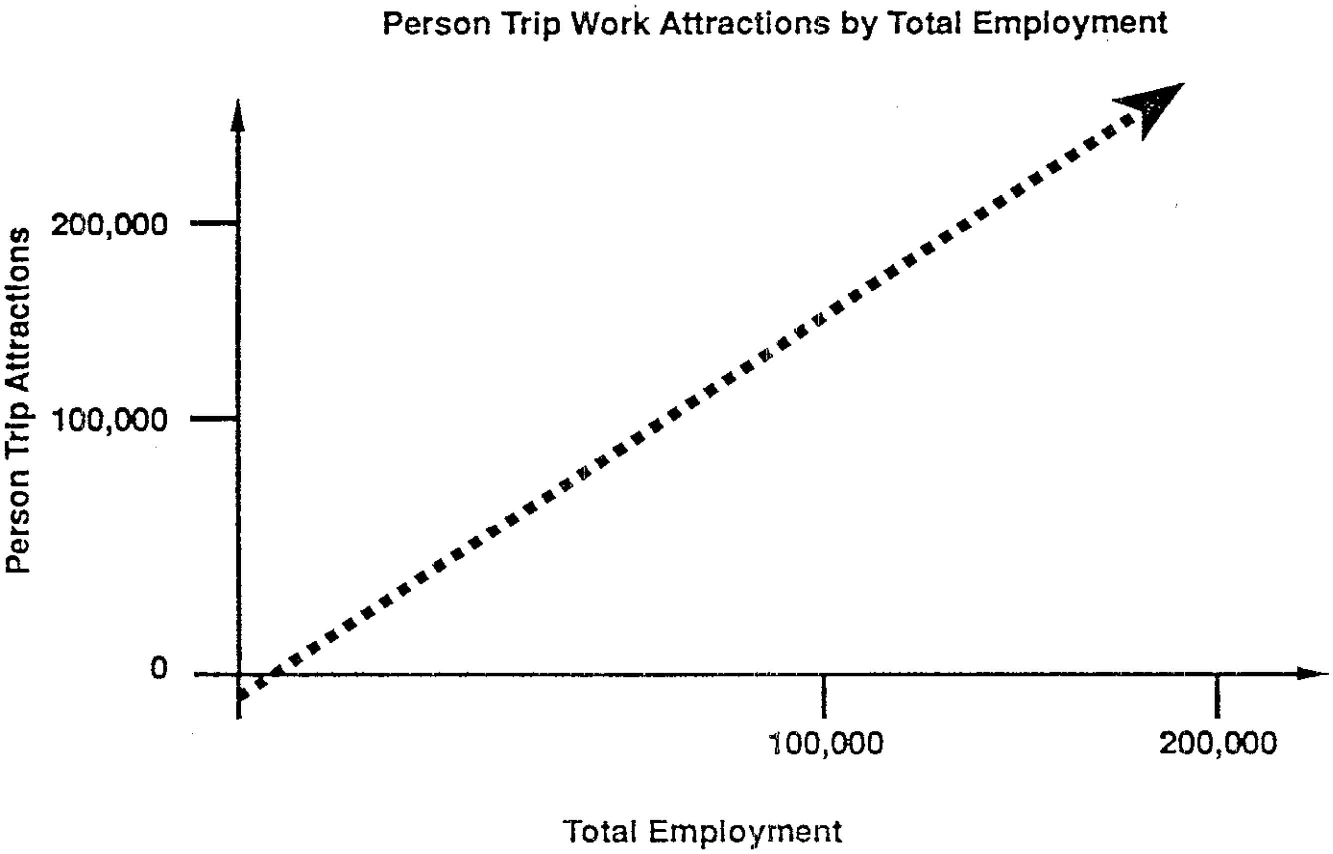
Relationship of Dwelling Unit Type and Auto Ownership to Average Work Person Trips per Household



Person Work Trip Rates by Auto Ownership and Dwelling Unit Type

Dwelling Unit Type	Auto Ownership		
	0	1	2+
Single Family	.002	.757	.809
Multi Family	.006	.727	.778

Figure 3-2a
Trip Generation Techniques
Cross-Classification Method



Trip Attraction Regression Equation

Trip Attractions = 1.478 * Total Employment –17.419

Figure 3-2b
Trip Generation Techniques
Linear Regression Method

Households with no Vehicles = Total Households * [0.24
- 0.22* (Single Family Households/Total Households)
-0.13* Ln(Population/Total Households)
+1.68* (1000/income)]

An example of a distribution curve is for zones in the low income group:

35% of households have low income
26% of households have low-medium income
22% of households have medium-high income
17% of households have high income

Internal-External and External-Internal Trips

Internal-external and external-internal trips are estimated using the same techniques as the internal trip purposes, but only for the internal portion of the trip. The external portion of the trip is set equal to the traffic count at the external station, less any external (through) traffic. The trip generation model uses this estimate of traffic at the external station as a "control" for the number of trips entering and exiting the study area at this location.

External Trips

External, or through, trips begin and end outside the study area, but travel through the study area at some point. Through trips are frequently estimated outside the trip generation model, using available data sources such as the Caltrans Statewide Travel Model or origin-destination survey data.

Special Generator Trips

Special generators are land uses that have significantly different trip rates than the general land use category trip rate associated with it. The ITE Trip Generation Manual (ITE, 5th Edition, 1991) provides trip rates for most specialized land uses. Traffic analysis zones may have land uses other than the special generator, which should estimate trips based on the trip production and attraction trip rates. One should be careful not to double-count special generator trips.

Special generator trips should, at a minimum, be estimated for military bases, airports and colleges.

3.2.3 Calibration

The calibration of the trip generation model generally occurs in three steps for each trip purpose: estimating trip productions, estimating trip attractions, and balancing the trip ends from each model. The calibration process will result in an identification of the significant variables and the trip rates or regression equations. The process may also include estimation of equations to strategy or distribute the variables by their socioeconomic characteristics.

The calibration process may result in the identification of significant variables that are difficult to forecast. As an example, if crime rate becomes a significant factor it may be useful in predicting the number of trips generated, but it may be difficult to forecast and could reduce the predictive abilities of the model if the forecast of the variable is inaccurate. Other variables may be considered that would capture the travel behavior and provide more confidence in the forecasts. Another example is provided in models that have developed sub-models to distribute the residential population into socio-economic groups, such as income stratifications, when the forecasts were only developed for average income. In this case, the forecast distribution of the population into income groups may be assumed to be the same as the distribution that is estimated in the base year. Variables that are difficult to forecast accurately should be avoided.

A number of commonly available statistical software packages can be used to estimate trip rates or regression equations from survey data and produce the necessary statistics to evaluate the model. Linear regression models have statistical measures to evaluate the goodness-of-fit. Unfortunately, there are no readily available statistical measures to assess the goodness-of-fit or reliability of the cross-classification method. One should consider the variability of the data within each cell of the classification scheme, because the cross-classification method is sensitive to the classification of each variable. The highest and lowest classifications are often less reliable, because of the relatively low number of observations typically found there. (Stopher & Meyburg,-1975).

Trip generation models should be calibrated from survey data and re-calibrated every ten years.

A reasonableness check of the model should identify if the trip rates or regression coefficients are consistent with behavioral theory. One example is whether trip rates increase with increasing income. Another example is the size of the constant in the regression equation. A final check might be whether the overall number of trips per household (or person) correlate to regional or statewide estimates.

The final step in the trip generation calibration process is to "match" the production and attraction trip ends. The trip distribution model requires that total productions equal total attractions. Typically, the attraction trip ends are scaled, or normalized, to equal the total number of production trip ends, based on the assumption that the trip production model is more reliable than the trip attraction model for the home-based trip purposes. The non-home-based trip purpose should be scaled using a different approach, that accounts for the fact that the non-home-based trip is often produced in a different zone than it is generated. If the non-home-based trip production model is estimated from household-based survey data then the model estimates non-home-based trips from households when the trip is, by definition, "not home-based." One approach to normalizing the non-home-based trips is a "re-allocation" of the trip productions from the zone of generation to the zone of attraction. The re-allocation process would then reflect the production of trips from the source of the activity.

The results of trip generation models are the number of trips produced or attracted in each analysis zone, by trip purpose. Figure 3-3 illustrates the trip production and attraction model results, by trip purpose, estimated for each socioeconomic data variable. Figure 3-3 presents the results of the trip productions and attractions before and after the scaling process to demonstrate the impacts of the scaling process on the total number of trip productions and attractions.

3.2.4 Validation

The validation process is designed to ensure that the trip generation model adequately replicates travel behavior under the range of conditions for which the model is likely to be applied. The time and cost involved in obtaining actual field data sources for the validation of the trip generation model may limit this type of validation. Validation includes comparing the results to other models and state or federal averages for consistency and reasonableness. Application of the trip generation model in a previous year, for which survey data are available, may provide a test of the temporal stability of the model.

Trip generation model results should be validated for total trips in each trip purpose and total person trips per household or per person should be compared to national or statewide sources or other regional models in California.

Land Use	Home-Based-Work		Home-Based-Other		Non-Home-Based	
	Prod.	Attr.	Prod.	Attr.	Prod.	Attr.
HOUSEHOLDS Family Size 0 - 0 Autos 1 Auto 2+ Autos						
1 - 0 Autos 1 Auto ⋮	100,000		150,000		20,000	20,000
5 - 0 Autos 1 Auto 2+ Autos						
EMPLOYMENT Total Retail Industrial Agricultural Office		110,000		140,000	40,000	40,000
Total (before balancing)	100,000	110,000	150,000	140,000	60,000	60,000
Total (after balancing)	100,000	100,000	150,000	150,000	60,000	60,000

(FIG3-3)

Figure 3-3
Trip Generation Model Application

3.3 TRIP DISTRIBUTION

3.3.1 Objective

The trip distribution step in the four-step process distributes all trips produced in a zone to all possible attraction zones. The model uses the number of trip productions and attractions estimated in the trip generation model and the transportation system characteristics to distribute the trips. The product of trip distribution is a set of zone-to-zone person trip tables stratified by trip purpose.

> *The trip distribution model should estimate person trip tables for each trip purpose.*

3.3.2 Model Specifications

A central assumption of the trip distribution model is that each traveler making a trip chooses a destination from all of the available destinations on the basis of the characteristics of each competing destination and the relative impedance associated with traveling to each destination. For each trip purpose, the destination choices will be determined by the relevant variables chosen in the model. The two most significant factors for destination choice are the relative attractiveness of a zone, measured by the number of attraction trip ends, and the relative impedance between the production zone and the attraction zone, measured as a function of time and cost. Other socio-economic factors, such as income or auto ownership, may influence destination choice and possible methods for including socioeconomic factors are presented in Chapter 5 as an area for further research. Figure 3-4 provides a graphic description of the process for development of impedance tables and a typical application of the trip distribution model.

> *Trip distribution models should distribute trips in a manner related to the attractiveness of alternate destination zones and inversely related to the impedance associated with traveling to each competing zone.*

State-of-Practice Methods

There are two types of trip distribution models in widespread use: gravity models and growth factor models (Fratar). One distinction between these methods is the data requirements. The gravity model requires data on the attractiveness of a zone (from the trip generation model), and the growth factor models require both a base estimate of origin and destination trips and a growth factor. Recently, there has been research into the applications of more behavioral choice-based distribution models (and this research is described in Chapter 5). The gravity model remains the most common trip distribution model in practice today. The growth factor (Fratar) model is frequently used for distributing external trips (through travel) or for producing incremental updates of trip tables when full application of the trip distribution model is not warranted.

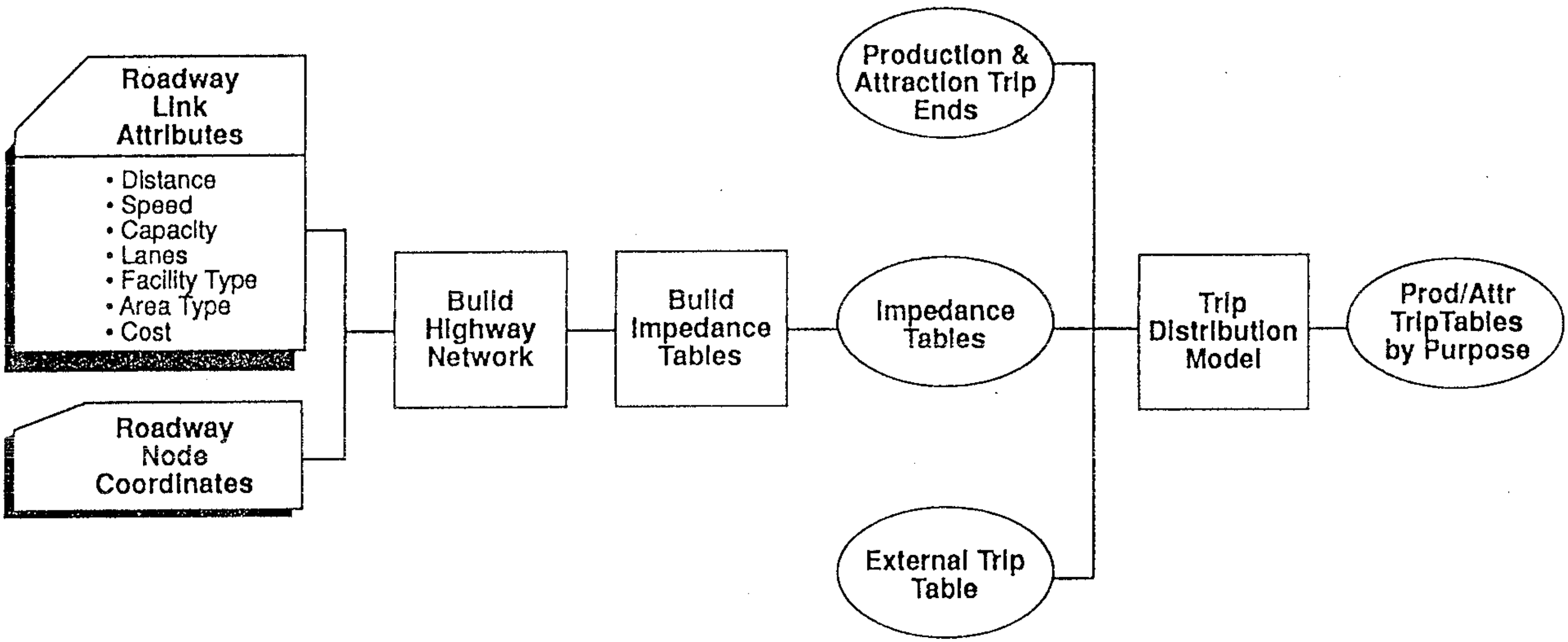


Figure 3-4
Trip Distribution Model and Impedance Tables

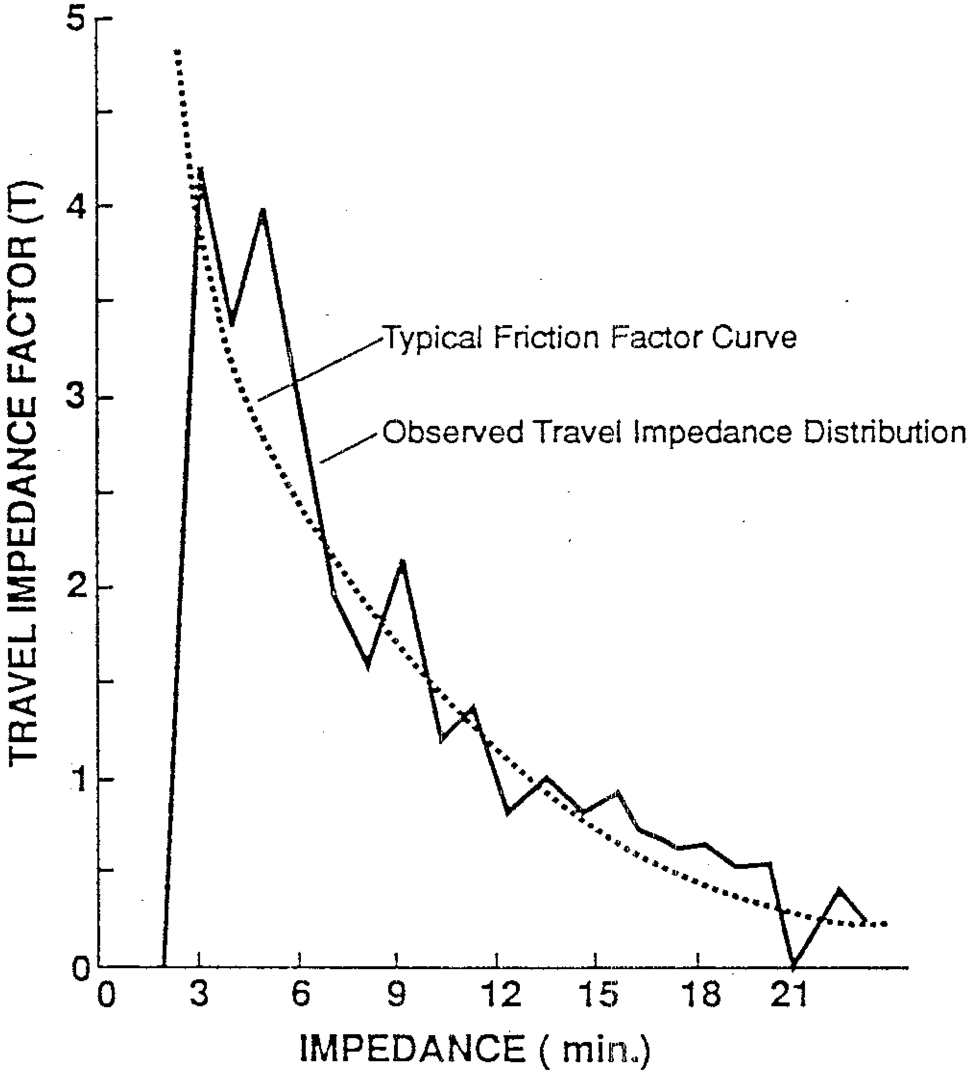
The gravity model is based on Newton's law of gravity, which describes the gravitational force between two bodies. The gravitational force, in transportation models, is a function of the attractiveness of a zone (measured in the number of trip attractions) and the impedance (measured as a travel time or friction factor) to the zone:

$$T_{ij}=P_i\frac{A_jF_{ij}K_{ij}}{\sum_n A_jF_{ij}K_{ij}}$$

where: T_{ij} = number of trips produced in zone i and attracted to zone j
P_i = number of trips produced in zone i
A_j = number of trips attracted to zone j
F_{ij} = travel time or "friction" factor
K_{ij} = zone-to-zone adjustment factor (takes into account the effect on travel patterns of defined social or economic linkages not otherwise incorporated in the gravity model)

The gravity model, in its traditional form, assumes that the trip productions are fixed and iterates to estimate the trip attractions in each zone. This procedure assumes people choose where to work or shop, based upon where they live.

The friction factor is developed from the travel impedance distribution as shown in Figure 3-5. Typically, application of the friction factor involves use of higher friction factors for shorter trips to demonstrate a realistic assessment of the propensity to travel. The use of travel demand models for air quality analysis has increased the need for accuracy of the friction factor curve for short trips because the friction curve has often been assumed to be a steadily decreasing function, instead of the actual travel impedance distribution, which is zero for trips of walking distance and then follows a similar function. (Further research on the separation of walk trips from other person trips is identified in Chapter 5.) The best-fit friction factor curve should reflect the full travel impedance distribution. Friction factors are calculated from a comparison of the estimated and observed trip length frequency distributions, and research has shown that these distributions (or the average trip length) remain relatively stable over time (Voorhees, 1968).



Source: Stopher & Meyburg, *Urban Transportation Modeling and Planning,* 1975.

Figure 3-5
Typical Travel Impedance Distribution

Growth factor models represent a simple form of the trip distribution model, based upon an expansion of existing interzonal trips by using growth factors. Growth factor models are generally used because of the limited data requirements. External (or through) trips that are not generated in or attracted to the study area are often distributed using this method.

The Fratar (growth factor) model should be used to forecast external, or through, travel.

Impedance

The gravity model requires a measure of impedance from each origin zone to each destination zone. Impedance generally represents the travel time, based on speed and distance, and cost, expressed in minutes (as a value of time). Many distribution models in the past defined impedance as the "free-flow" or uncongested travel impedance for all trip purposes volume-to-capacity ratio on a route segment but more accurate representation of impedance may be warranted for many applications. Impedance values have been constructed to reflect --

- o congested or uncongested time periods
- o a composite of highway and transit travel impedances
- o a composite of travel time and cost

Most regional models in California use congested travel time for the home-based work trip purpose and all other trip purposes use the uncongested travel time. Methods are available to use a volume-weighted combination of congested and uncongested travel impedance appropriate for each individual trip purpose, but this process is not widely used in California.

Trip distribution models should use a value for impedance that is based on realistic estimates of travel time and speed. Impedance values should reflect those used in the calibration process.

Advanced models should incorporate a feedback loop from trip assignment to trip distribution when there is evidence that congestion significantly affects impedance. Uncongested travel impedances input to trip distribution are acceptable if the impact of congestion is not significant.

Most trip distribution models in California have been developed with the assumption that the highway travel impedance is a sufficient representation of travel impedance for estimating destination choice and that the development of a composite highway and transit travel impedance is not sufficiently cost-effective to justify the extra effort required. The definition of travel impedance as a composite of travel time and cost has been used commonly in California to include cost for toll facilities, but exclude operating cost.

The trip distribution model should use a value of impedance that is derived from the highway travel time and should include cost if toll facilities exist in the network or are being evaluated.

K-Factors

K-Factors are the zone-to-zone adjustment factors that account for social or economic linkages that impact travel patterns but are not reflected accurately by the gravity model. One example of an economic situation affecting travel patterns is the proximity of blue collar neighborhoods near a central business district to the white collar jobs in the same area. The gravity model may overestimate trips in this case, based on the short travel impedances, when the actual travel patterns may be quite different.

Unfortunately, the use of K-Factors reduces the credibility of the forecasts because they limit the response of the model to the variables such as travel time and cost that are likely to vary over time. As a result, they should be used sparingly and cautiously. A few K-Factors may be justified for specific social or economic linkages that impact travel patterns.

> ***Trip distribution models should minimize or eliminate the use of K-Factors in gravity model applications.***

Intrazonal trips

Intrazonal trips represent trips made totally within a zone. They are assumed to travel only on local streets and are not assigned to the roadway network during trip assignment. The estimation of the vehicle-miles-traveled due to intrazonal trips is easily calculated if desired or essential to the analysis. One example is the use of travel models for emission inventories for which intrazonal travel can have a significant impact on total regional emissions but little impact on major transportation facilities.

Intrazonal impedances are typically estimated using the nearest neighbor method, which uses half of the travel impedance to the nearest zone as the intrazonal impedance. These may be adjusted to reflect terminal impedances or the time spent outside the vehicle at the beginning or end of the trip. The number of intrazonal trips are generally determined by applying the gravity model, but other methods include assuming that a fixed percentage of the trips by purpose will be intrazonal regardless of zone size.

> ***Trip distribution models should estimate intrazonal impedances using the nearest neighborhood method, or other reasonable estimation of intrazonal trips, by purpose.***

3.3.3 Calibration

The calibration of the gravity model involves the estimation of friction factors (F_{ij}) and zone-to-zone adjustment factors (K_{ij}). In the first iteration of the gravity model calibration, the F_{ij} and K_{ij} are set equal to one. The friction factor is then calculated from the comparison of observed to model-estimated trip length frequency distributions, using a manual adjustment of the curves or variety of mathematical functions. Most calibration processes require an iterative procedure to estimate the friction factors. Two of the functions used to estimate friction factors are the gamma function:

$$F = a * I^{b} * e^{cI}$$

and the negative exponential function:

$$F = a * e^{-bI}$$

where: F is the friction factor
a,b,c are calibrated model coefficients
I is the impedance

K-factors can be calculated from a comparison of observed trips to estimated trips for a zone-to-zone (or district-to-district) interchange, but should represent only explanatory differences in socio-economic data from one area to another, rather than zone-to-zone adjustment factors used to improve the model results.

Trip distribution models should be calibrated at least once every ten years, based upon available survey data.

3.3.4 Validation

The validation procedure for the trip distribution model is similar to the validation of the trip generation model. Due to time and cost limitations in collecting data other than that used in calibration, the validation process often relies on the verification of consistency and reasonableness to available data sources. Back-casts to a previous year, for which survey data are available, often does provide a test of the temporal stability of the model.

Trip distribution models should be validated by comparing the average trip length for each trip purpose to national or statewide averages and other regional models in California and, where possible, by applying the model for another year for which survey data are available.

3.4 MODE CHOICE

3.4.1 Objective

The mode-choice model separates the person trip table into the various alternative modes, by trip purpose. The available modes have expanded in recent years to include stratifications of the auto mode by vehicle occupancy (drive alone, two occupants, three occupants, etc.); and the stratification of transit modes into transit technologies and types of operation, (local bus, express bus, light rail, heavy rail, etc.); and types of access (walk or drive).

The mode choice model should estimate person trip tables by mode and purpose.

3.4.2 Model Specifications

The mode choice model estimates a traveler's choice between modes, based on characteristics of the traveler, the journey, and the transportation systems. The traveler characteristics affecting mode choice include auto ownership, income, workers per household, and trips for more than one purpose (chained trips); the journey characteristics are the origin and destination, the trip purpose and the time of day the trip is taken; and the transportation characteristics include travel time (in and out of the vehicle), costs (fares and auto operating costs), and availability and cost of parking, as well as comfort, convenience, reliability and security.

Traveler characteristics should include the significant variables affecting mode choice. These most often include income and/or auto ownership.

The characteristics of the journey are a function of the trip purpose and the time of day when the trip is taken. For simplicity, many mode-choice models assume that trip purpose defines when the trip is taken, i.e., that all home-based-work trips occur in the peak period and all other trip purposes occur in the off-peak time period. This assumption allows peak impedance tables to be used for the home-based-work mode-choice model and off-peak impedance tables to be used for other purposes.

The characteristics of the transportation system include travel times (in-vehicle and out-of-vehicle travel times) and costs (out-of-pocket, maintenance and operating costs) as well as performance-related variables that are difficult to quantify, such as comfort, reliability, and security. Transit travel times should include time spent driving to transit, as well as time spent in transit vehicles. Out-of-vehicle travel time should be classified by function for transit: waiting time, walking time, time to transfer, etc.; and classified by terminal end for highway: origin terminal time and destination terminal time. Transit mode of access (walk or drive) can be included in mode-choice models in addition to access travel times.

In small and medium-sized regions in California, the transit modal share is small enough that the effort involved in developing a behavioral choice model for mode choice is often is not justified by the benefits the model provides. A simplified approach is to estimate district-to-district factors representing the transit, carpool, and drive-alone modal shares (based on observed values for a baseline year or an external estimate for a future year) and apply them to each trip table, by purpose. The method is acceptable if the regional agency is not involved in testing the sensitivity of carpool or transit policies.

The mode-choice model should be consistent with good econometric practice and should remain an unbiased estimator of trips by mode and purpose. The method should include significant variables, and provide sensitivity to policy variables. Application of district-to-district factors for vehicle occupancy or transit mode shares is acceptable if the regional agency is not testing the sensitivity of carpool or transit policies.

Discrete choice models, where the choice between modes is limited to the number of available modes, have been well researched (Ben-Akiva and Lerman, 1985, and Hensher and Johnson, 1981, and Stopher and Meyburg, 1976) and may be the most common modeling methodology used in mode-choice models. Discrete choice modeling allows the incorporation of all significant variables, which reduces the bias from influences not included in the model. The remainder of this section covers the specifications for discrete choice and incremental mode-choice models.

Discrete Choice Models

The predominant mode-choice model in use today is a logit model, a form of discrete choice model based on the behavior of travelers within a particular market. Logit models predict the "choice" that a traveler will make based upon travel times and costs, socio-economic information on the traveler, and other unique characteristics of the trip. The process for application of the mode-choice model is graphically illustrated in Figure 3-6. Work mode choice models vary from non-work mode choice models based on the peak and off-peak transportation services available for these trip purposes.

The logit model is based on the assumption that an individual associates a utility with each alternative in a choice set. The individual then will select the alternative which provides him or her the highest utility. The utility, U_{in}, which individual n associates with alternative i has two components; a systematic component, V_{in}, which can be represented analytically as a function of observable characteristics of the individual and the alternative, and a random component, e_{in}. This random component results from unobserved attributes of the alternative, such as taste variations among individuals and inaccuracies in the specification of the systematic component of the utility.

An assumption of the logit model is that the random components of the utilities are independent and identically distributed. An additional assumption that distinguishes logit from other probabilistic discrete choice models is that the random components also have a Gumbel *distribution. (Ben-Akiva and Lerman, 1985)*

The characteristics of the logistic curve for mode-choice models are derived by relating the systematic utilities that individual n associates with each mode to probabilities of choosing a particular mode. For a binary choice:

$$P_n(i)=\frac{\exp(V_{in})}{\exp(V_{in})+\exp(V_{jn})}$$

where: $P_n(i)$ = the probability that individual n will chose mode i
V_{in} = the systematic utility that individual n associates with mode i

V_{jn} = the systematic utility that individual n associates with mode j

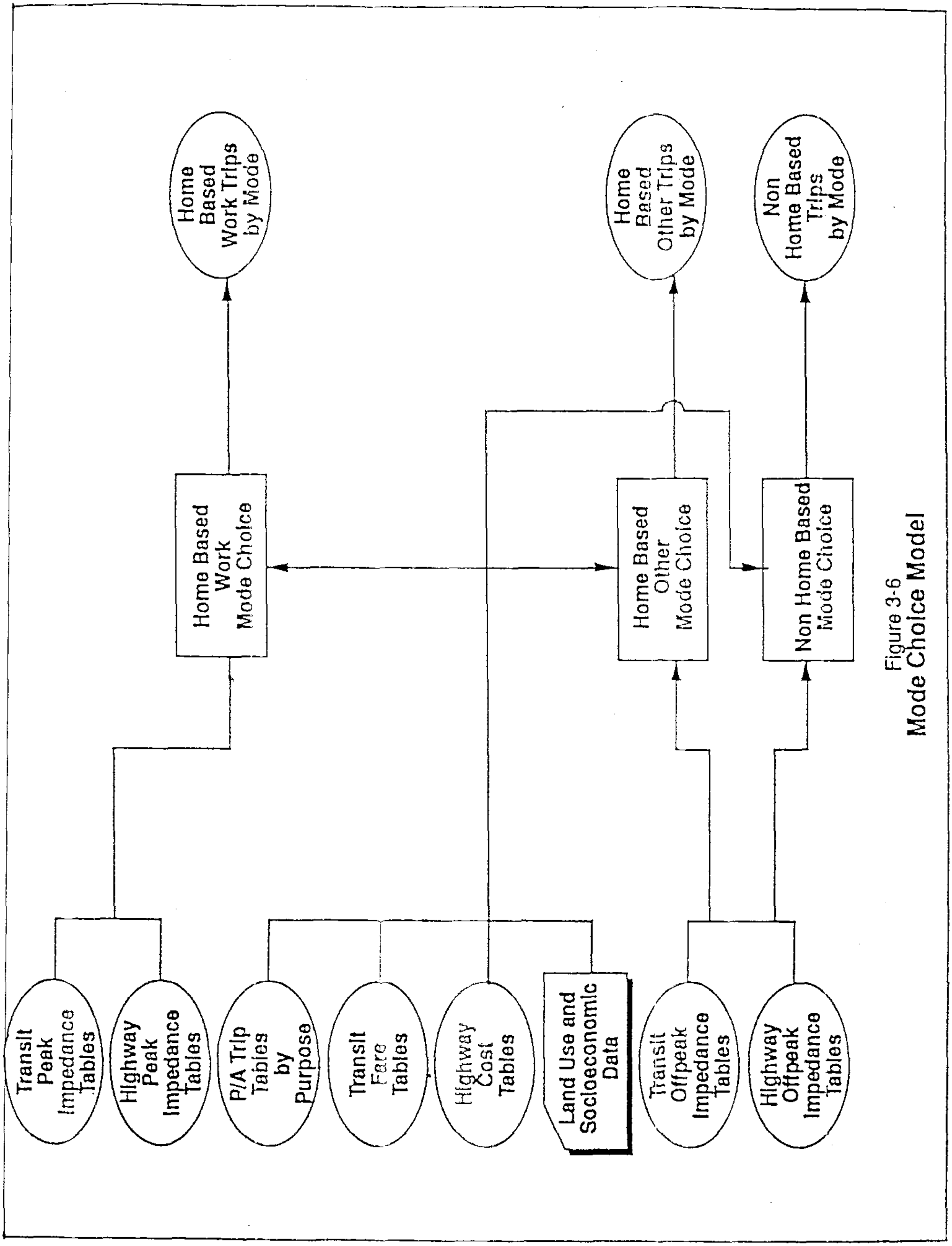


Figure 3-6
Mode Choice Model

In the case of a multinomial choice model, the formulation is:

$$P_n(i)=\frac{\exp(V_{in})}{\sum_{j\epsilon J_n}\exp(V_{jn})}$$

where: $P_n(i)$, V_{in} = as defined above
V_{jn} = the systematic utility that individual n associates with mode j_J_n
Σ = the summation over all modes available to individual n and denoted by J_n

The utility function allows any number and specification of the explanatory variables, as opposed to the case of the generalized cost function in conventional models which are generally limited and have several fixed parameters. This allows a more flexible representation of the policy variables considered relevant. The coefficients of the variable reflect the relative importance of each attribute (Ortuzar and Willumsen, 1990).

An assumption implied by the use of the logit form is the independence from irrelevant alternatives (IIA) property. The independence assumption can be violated if two or more alternatives are correlated in their unmeasured attributes. This may result from incorrect or incomplete specification of the utility function. This can easily happen when two alternatives are perceived by the decision-maker as being very similar in some unobserved attribute.

If there exists a high correlation in the unobserved attributes of two or more alternatives in a choice set, a bias in the parameter estimates will result. There are two approaches which can reduce or eliminate bias. The first, which retains the logit model structure, is to "nest" the choice model; first modeling the choice among the alternatives with high correlation in unobserved attributes and then modeling the choice of primary alternatives (grouped alternatives). The second approach is to drop the logit formulation entirely and use instead a probit formulation which explicitly incorporates the correlation between alternatives in the model. The use of the probit structure is analytically more complex and can be prohibitively expensive to estimate if the number of alternatives is large.

The logit model assumes that the error terms are independent across alternatives. If there are unobserved attributes shared by two or more alternatives in a choice set which results in correlation in one of the components of the error term, the conditions necessary for the logit model may be violated. The direction of the nesting structure then depends on which choice has correlated unobserved attributes. One example of a nested mode choice model structure is presented in Figure 3-7.

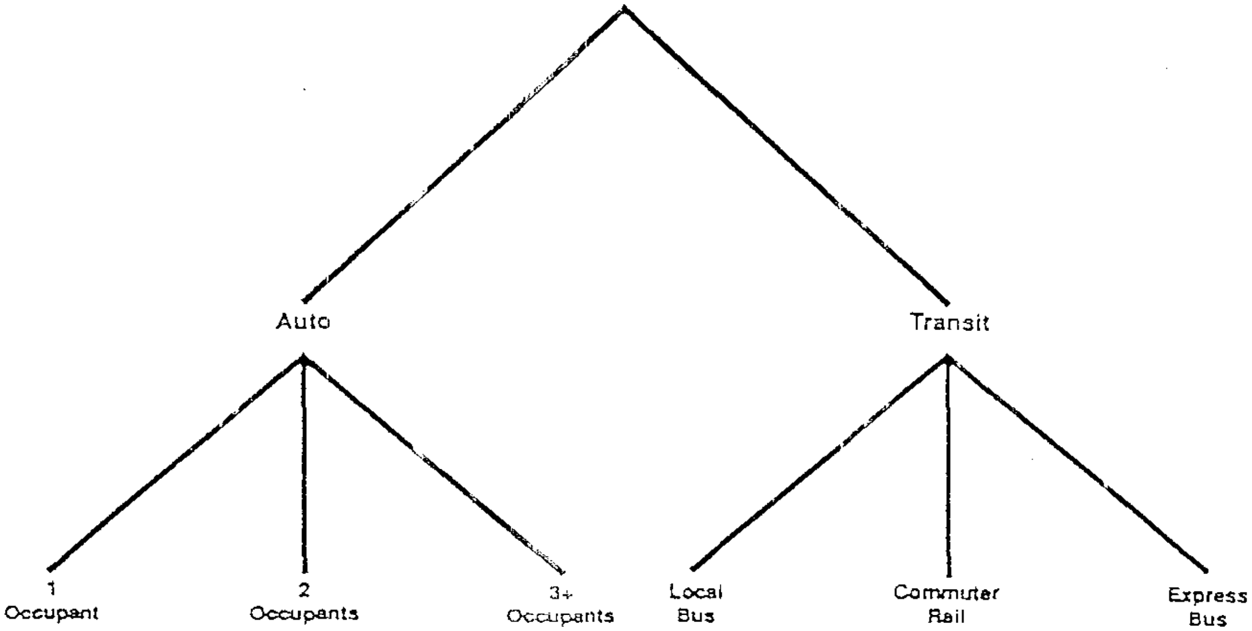


Figure 3-7
Nested Mode Choice Model Structure

Ben-Akiva and Lerman (1977) and McFadden (1973) have demonstrated that when a nested logit structure is appropriate, the models can be estimated sequentially. They showed that a logit model of the choice for which there are shared unobserved attributes for alternatives with common choices of x (which suggests the first nesting structure) can be estimated as a marginal probability model for the choice of X:

$$p_x(x)=\frac{\exp[(V_{xn}+w(\Gamma_{xn})]}{\sum_{x'\in X_n}\exp[(V_{x'n}+w(\Gamma_{x'n})]}$$

where: $p_n(x)$ = the probability that individual n will chose x from the choice set X_n
V_{xn} = as before
w = a scale parameter that measures the relative variance of e_{xy} and $(e_x + e_{xy})$
and:

$$\Gamma_{xn}=\log\sum_{y'\in Y_{xn}}\exp[(V_{xy'n}+V_{y'n})]$$

which is designated LOGSUM (x) and is equal to the natural logarithm of the denominator of the conditional probability

If the independence from irrelevant alternatives (IIA) assumption is correct, then the multinomial logit structure can be used in lieu of the nested logit structure.

Incremental Mode-Choice Models

The incremental mode choice model provides a method to analyze the impact of changes in fares, levels of service, or other attributes of a mode on mode split when baseline mode share and baseline values of the attributes are known. There are two types of incremental mode choice models: incremental elasticity and pivot-point. Incremental elasticity analysis uses a sensitivity factor (percentage change in mode share that will result from a one percentage change in an attribute) that can be based on a logit model or can be based on observed response to changes in an attribute. Pivot-point mode-choice models use the multinomial logit model and the changes in the level-of-service variables (only for those variables that are expected to change). Further information on incremental models can be found in Ortuzar and Willumsen (1990).

The incremental approach has the advantage of forecasting mode shares directly from the actual (existing) mode shares, as opposed to full discrete-choice models that forecast mode shares based on relative travel times and costs for each mode. In contrast, the discrete-choice models can provide more insight for new modes that are not adequately represented in existing mode shares, such as HOV trips where there are currently no HOV facilities.

3.4.3 Calibration

The calibration of the mode choice model should produce estimates of the coefficients and the bias constant in the modal utilities in the logit equation. One example of a typical utility equation for the transit impedance can be found in the Procedures and Technical Methods for Transit Project Planning (UMTA, 1990):

Transit utility = - 0.5 (bias constant)
- 0.02 * transit in-vehicle travel time
- 0.04 * transit out-of-vehicle travel time
- 0.008 * transit fare/household income
- 1.5 * autos owned
- 1.0 (0 if walk access, 1 if drive access)

After specifying the available set of alternatives and the variables to consider the calibration of the mode choice model should produce the utility function for each mode alternative. There are available software packages to estimate multinomial and nested logit models.

Goodness-of-fit measures test the performance of the model in predicting mode choice by comparing predicted volumes to observed data. The t-test will determine the significance of any variable in the modal utility equation. The coefficient of the variable is significantly different than zero at the 95% confidence level if the absolute value of the t-score is greater than 1.96. The sign of the coefficient is also a test of the expected impact of the variable on the utility equation (or the utility equations is improperly specified). If it is an incorrect sign, the variable should not be used in the utility equation. If the sign is correct and if the coefficient on the variable is significant, the variable can be included in the utility equation. Policy variables can be included in the utility equation if the sign is correct, even if the coefficient was not significant, because the lack of significance could be caused by lack of variability in the data. One additional test is the log-likelihood ratio test. In this test, a variable improves the overall performance of the model if the log likelihood ratio decreases.

If a nested logit model structure is being evaluated, various combinations of nested structures should be tested and compared to the original multinomial structure. These tests will ensure that the model structure chosen is appropriate for the area being modeled. Also it is important to discern whether the nested structure significantly improves the model performance compared to the multinomial structure, otherwise it may not warrant the additional effort involved.

Mode choice models should be calibrated at least once every ten years. Nested model structures should be evaluated in advanced models used to evaluate carpool alternatives or multi-modal transit systems.

3.4.4 Validation

The validation process for the mode-choice model involves identifying a validation data source, that is different than the calibration data source, and comparing observed modal splits with model-estimated modal shares by districts. Again, the cost-effectiveness of collecting data for validation limits the ability to validate using actual data, but application to a prior year or to a segment of the calibration dataset can provide a text of the sensitivity of the model. Similar to the validation procedure for trip generation and distribution, validation for mode-choice models should rely on the consistency and reasonableness of the results compared to available data sources.

Mode-choice models should be validated using available estimates from national, statewide, or regional sources of transit or carpool mode shares, by purpose. Assignments of the transit or carpool mode shares may be used to compare the results to on-board surveys or actual traffic counts.

3.5 TRIP ASSIGNMENT

3.5.1 Objective

The objective of the trip assignment model is to assign the various modal trip tables to the alternative paths or route available. Typically, transit trips are assigned to the transit network where path choice includes all transit modes, and vehicle trips are assigned to the highway network, where path choice is affected by various use restrictions for HOV or truck trips.

The trip assignment model should produce estimates of vehicular traffic assignments on the roadway network and person trip assignments on the transit network.

3.5.2 Model Specifications

Trip assignment models use impedance to determine path choice for each mode. The methods for trip assignment vary by mode: highway and carpool (HOV) assignments, and transit assignments. The assignment methodologies for each are determined by the structure of the network, available path-building algorithms, and capacity restraint capabilities.

Impedance

The highway network characteristics contain data to determine the travel impedance for each path, or route, where travel impedance is defined by some combination of travel time and cost. The travel impedance is defined in Section 3.3.2 for the trip distribution model.

The value of speed used in calculating travel impedance should represent average observed uncongested speeds identified as "free-flow" speeds. The application of the trip assignment results in an estimate of congested speeds.

In the past, models would input free-flow link speeds and adjust this value during validation of the model. The performance of the trip assignment model has historically been based on accurate link volumes, and the adjustment of speeds was used to assist in this goal. The objective of travel demand forecasting models has shifted to include producing data for emissions inventories, which are dependent upon accurate estimates of speeds. This additional purpose of estimating accurate speeds in the trip assignment model may change the requirements for the input travel impedance.

Travel impedance values in the trip assignment model should represent the travel time (and cost for areas with toll facilities), along a link, calculated from the average observed uncongested speed along a facility, including intersections and other average delays. The average observed uncongested speed should not include any delays due to congestion.

Capacity

The capacity of a roadway link is affected by the level-of-service on the link. The capacity of a freeway link at level-of-service E may be 2,000 vehicles per lane per hour, when the capacity of the same freeway link at level-of-service C might be 1,750 vehicles per lane per hour. Typically, travel demand forecasting models use link capacity defined by level-of-service C or D. The capacity will impact the congestion on a link, defined by the volume-to-capacity ratio, and also the delay on the link, caused by congestion.

Highway Assignment

Highway assignment models load the vehicle trips onto the highway network using a range of path-building algorithms, and typically iterate each assignment to account for congestion on the system. There are two path-building algorithms in wide use: all-or-nothing and stochastic (or multi-path). The all-or-nothing algorithm assigns all of the trips to the minimum path and should only be used in combination with iterative, incremental, averaging or equilibrium methods to further adjust the assignments. The stochastic algorithm estimates a probability that a trip will take the minimum path or some other "efficient" path, and assigns proportions of the total trips to various paths based upon the estimated probabilities. This technique was popular for some time based on its ability to capture travel behavior more effectively than the all-or-nothing algorithm, but the stochastic assignment cannot produce turning movements for intersection capacity analysis or selected-link assignments. These limitations significantly restrict use of the model.

The iterative process used in highway assignment models provides a variety of methods to combine the results of each iteration: equilibrium, incremental and averaging. The equilibrium method first developed by UMTA in the UTPS programs, is an optimization procedure, that searches for the best combination of the current and previous iterations. Equilibrium is said to be achieved when no trip can reduce travel impedance by changing paths. The incremental approach combines the previous iteration with a fixed percentage of the current iteration. Certain applications of the incremental method will update speeds for capacity restraint based upon a full assignment of the trips, but keeps only the fixed percentage identified in the increment. The averaging method combines the results from one iteration with the results of other iterations, to produce a volume-weighted average assignment across all iterations.

The most common highway assignment models include adjustments to the travel time or speed estimated for each path based on congestion, defined by the volume-to-capacity ratio. This is generally termed a capacity restrained assignment. These adjustments are made through volume-delay equations, that estimate the delay associated with traffic volumes for each segment in the system. These volume-delay equations most frequently have one of two forms: the Bureau of Public Roads (BPR) equation and the exponential equation as follows:

BPR Equation:

$$Delay = Impedance * A \frac{(V/C)^c}{B}$$

defaults:
A = .15
B = 1.0
C = 4

Exponential Equation:

$$Delay = Length * minimum\ (A * exp\ (B*VC), C)$$

defaults:
A = .02
B = 4.0
C = 60 minutes/mile limit

where: Impedance = average observed uncongested travel time and cost
VC = volume-to-capacity ratio
Delay = average vehicle delay
Length = link length

Figure 3-8 presents the volume-delay curves plotted for the two equations using the standard default values.

> *Various assignment highway path building algorithms, iterative techniques, and volume-delay equations should be tested to determine the trip assignment model that produces the closest match to actual traffic counts while remaining behaviorally consistent and producing useful output reports.*

HOV Assignments

High-occupancy-vehicle (HOV) trips, estimated with the mode-choice model, can be assigned to the highway network simultaneously with low-occupancy-vehicle (LOV) trips, or sequentially before or after the LOV trips. HOV trips are defined as any vehicle trip for which the occupancy level is sufficiently high to satisfy restrictions on HOV links in the system. In some regions this may vary by facility. Low-occupancy vehicle trips may be drive-alone only or drive-alone and two-person carpool depending on the facility-specific definition of HOV. Another frequently used term, single-occupant-vehicle (SOV), refers only to the drive-alone mode. The preferred method loads the HOV trips simultaneous with the LOV trips. This method provides equal opportunity for HOV trips to use LOV facilities and causes LOV trips to consider HOV volumes in selecting the best paths, which can be critical on arterial approaches to HOV facilities. The sequential approach gives preference to the trip table assigned first, but may be useful if software packages do not support the simultaneous method.

Transit Assignment

The transit assignment procedures predict the route choices for the transit trips. The choice of a transit route is influenced by different attributes of the transit network, all of which affect the overall travel impedance. The perception that time spent outside a vehicle or time spent transferring from one vehicle to another is more onerous than time spent riding in a vehicle affects the weight of these variables in the impedance function but both types of travel time should be included.

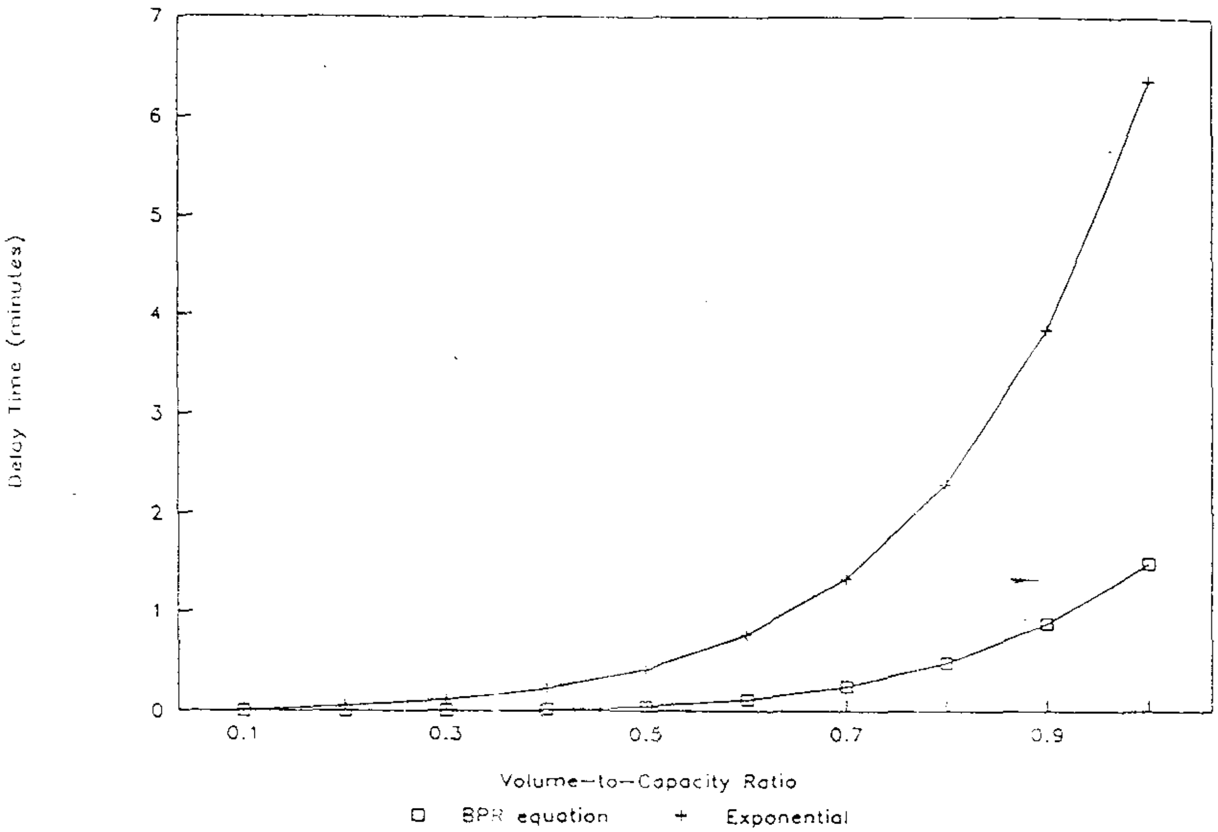


Figure 3-8
Volume-Delay Curves for Capacity Restraint

There are three issues that warrant discussion concerning transit assignment: supply of transit services, estimated cost of transit service to the passenger, and the definition of generalized impedance. The supply of transit services is defined by the capacity of a transit vehicle and its corresponding frequency. The transit network consists of route segments (links) and transit stops (nodes) that form transit routes (lines). The estimated cost of using a transit service is the average fare paid to take the trip, including transfer fares. If discounted fares are significant, the average fare should reflect these discounts.

The generalized impedance is a function of the in-vehicle travel time (IVTT), the time spent waiting for a vehicle (WAIT), the time spent walking to the transit stop (WALK), the time spent transferring from one route to another (XFER), including a penalty to represent resistance to transferring (XPEN), and the fare (FARE):

IMPEDANCE = a*IVTT + b*WAIT + c*WALK + d*XFER + a*XPEN + e*FARE
Where: a,b,c,d,e are coefficients associated with the impedance.

The coefficients on the out-of-vehicle travel times (WAIT, WALK, XFER) can be two to three times the value of the coefficient on in-vehicle travel time.

Transit assignment techniques may vary from one software package to another, but the most common path-building algorithm is the all-or-nothing method. This method chooses the minimum impedance path based on the generalized impedance function. The all-or-nothing method can overestimate routes with a high frequency of service or underestimate routes that are highly competitive, but are not on the minimum path. Modeling the path choice or using a multi-path transit path-building algorithm are possible solutions to the weakness of the all-or-nothing algorithm. Another issue in transit assignment is the assumption that capacity does not limit transit route choice or assignment. Prashker (1990) investigated the possibility of restraining transit assignments to available capacities, as well as incorporating a multi-path path-building algorithm.

Further guidance on transit assignment techniques may be found in the "Procedures for Transit Project Planning," (UMTA, 1990) and Modeling Transport (Ortizar and Willumsen, 1990). The objective of the transit trip assignment model is to reflect the impact of transit vehicles on congestion and air quality, but the transit assignments process assigns transit person trips, not transit vehicles. The assignment of transit vehicles is determined by a combination of operational policies and travel demand. For the purposes of air quality analysis, the transit travel demand model is relatively insensitive to the assignment of transit vehicles and the resulting air quality.

3.5.3 Calibration and Validation

Technically, the separation of calibration and validation of the trip assignment model is difficult because there is generally only one data source available for both exercises. In practice, the calibration of the highway assignment model includes identifying the model specifications and adjusting the volume-delay equations to adequately represent the region. The validation of the model includes checking the accuracy of any link data assumptions and evaluating the reasonableness of the input data (network or zone based) by comparing the model estimated assignments to traffic counts. It is important to recognize that traffic counts are themselves only estimates of traffic volume and should be tested for reasonableness during validation along with the other input data. Counts could have errors caused by variation in the mix of vehicles or may not have been adjusted for season or day-of-the-week variations. Errors could also be due to mechanical counter failure, field personnel mistakes, or improper count location.

Traditionally, highway assignment models have been calibrated and validated based primarily on the comparison of estimated model volumes to traffic counts. The calibration results can be summarized from the model estimated volumes on link segments and compared to traffic counts for various facility types and for facilities experiencing congestion. Adjustments to the volume-delay equation or the trip assignment method can impact general over- or under-estimations of link volumes. The validation effort involves more link-specific summaries of model-estimated volumes compared to traffic counts, either by screenline or by district or by individual link. Errors found at this step in the modeling process can lead to adjustments in the modeling process which may compensate for assignment/ground count differences. Inaccurate screenline estimates may imply incorrect trip distributions, inaccurate district estimates can imply incorrect trip generation rates or equations and inaccurate link estimates can imply incorrect network characteristics. Incorrect mode-choice estimates may also affect any or all of the above.

The regional agency should strive to obtain traffic counts on ten percent or more of the regionwide highway segments being analyzed, if resources allow. This ten percent goal applies also to the distribution of counts in each functional classification (freeways and principal arterials, at a minimum). Validation for groups of links in a screenline should include all highway segments crossing the screenline.

Calibration and validation of the transit assignment model follows the same procedures as the highway assignment model, except that transit ridership counts would replace traffic counts. Again, inaccurate estimates can imply incorrect assumptions used in path-building or mode-choice.

There are many statistics that can be helpful in calibrating or validating trip assignment models: absolute difference, percent difference, average error, average percent error, standard deviation, R squared, root mean square error and the correlation coefficient. The statistics are helpful in determining the overall performance of the trip assignment model, and the four-step travel demand forecasting process.

A test of the percent error by functional classification will provide insight into whether the assignment model is loading trips onto the functionally classified systems in a reasonable manner. The percent error by functional classification is the total assigned traffic volumes divided by the total counted traffic volumes (ground counts) for all links that have counted volumes, disaggregated by functional classification. Suggested error limits are:

Suggested Regionwide Validation Criteria

Functional Classification	Percent Error
Freeways	Less than 7 percent
Principal Arterials	Less than 10 percent
Minor Arterials	Less than 15 percent
Collectors	Less than 25 percent
Frontage Roads	Less than 25 percent

Source: FHWA Calibration & Adjustment of System Planning Models; December 1990

The correlation coefficient estimates the correlation between the actual ground counts and the estimated traffic volumes and is produced by most software packages.

Suggested Regionwide Correlation Coefficient > 0.88.

The vehicle-miles-traveled is a significant factor for emission inventories and should be compared to available data sources, such as the Highway Performance Management System (HPMS). HPMS and other estimates of regional estimates of VMT are also subject to estimation error and are reasonable only as verification of consistency and do not provide a useful measure of the accuracy of the model system.

The validation process should also include the comparison of ground counts to estimated volumes on individual freeway and principal arterial links, as well as screenlines defined to capture the travel demand from one area to another. Figure 3-9 presents the maximum desirable deviation for individual link volumes and total screenline volume. Figure 3-9 also shows the approximate error in a single traffic count for individual links.

The suggested link-specific validation criteria is that 75% of freeway and principal arterials and all screenlines meet the maximum desirable deviation in Figure 3-9.

3.6 TIME-OF-DAY DISTRIBUTION

The allocation of travel to specific time periods can occur at various stages within the four-step modeling process, but the most common application is to develop time period specific trip tables after mode-choice.

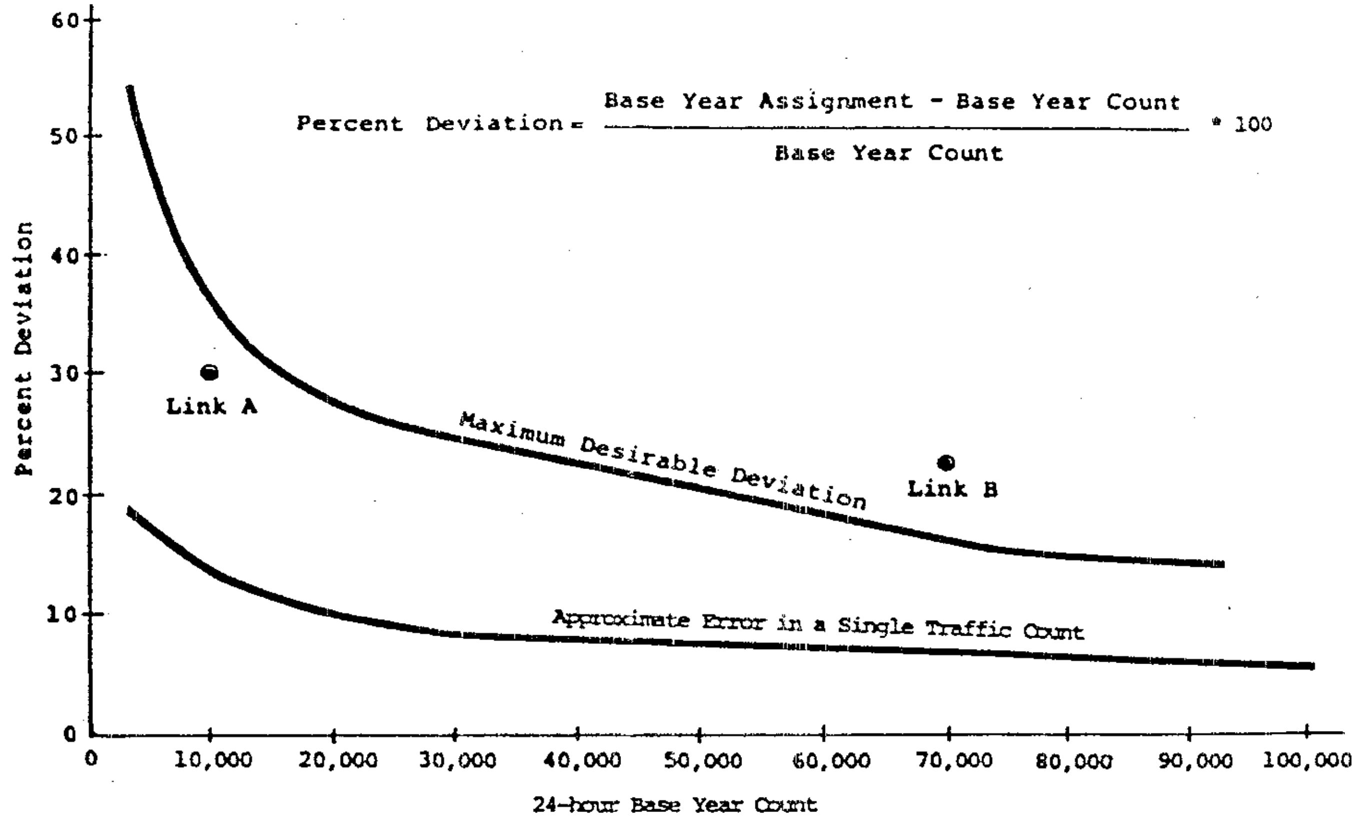
Time-period specific trip tables should be developed for severely congested time periods in the day and should be identified by the nature of the difference between impedances from one time period to another as peak-period or peak-hour tables.

Peak-period trip tables represent all trips within a one- to four-hour period of peak travel. Peak-hour trip tables represent the highest hour of travel within the morning or afternoon time periods. Peak spreading is a phenomenon that occurs when the capacity of the transportation system is severely constrained in the highest demand portion of the peak period. To avoid severe congestion, travelers choose to make trips earlier or later and a spreading of the peak occurs. The result is usually a longer peak (congested) period and a more even distribution within the peak period. If peak spreading has occurred, then a separation of the peak-periods into individual peak-hours is often not warranted. If the level of congestion in the peak-hour is significantly different than the average conditions in the peak-period, then the peak hour should be estimated separately.

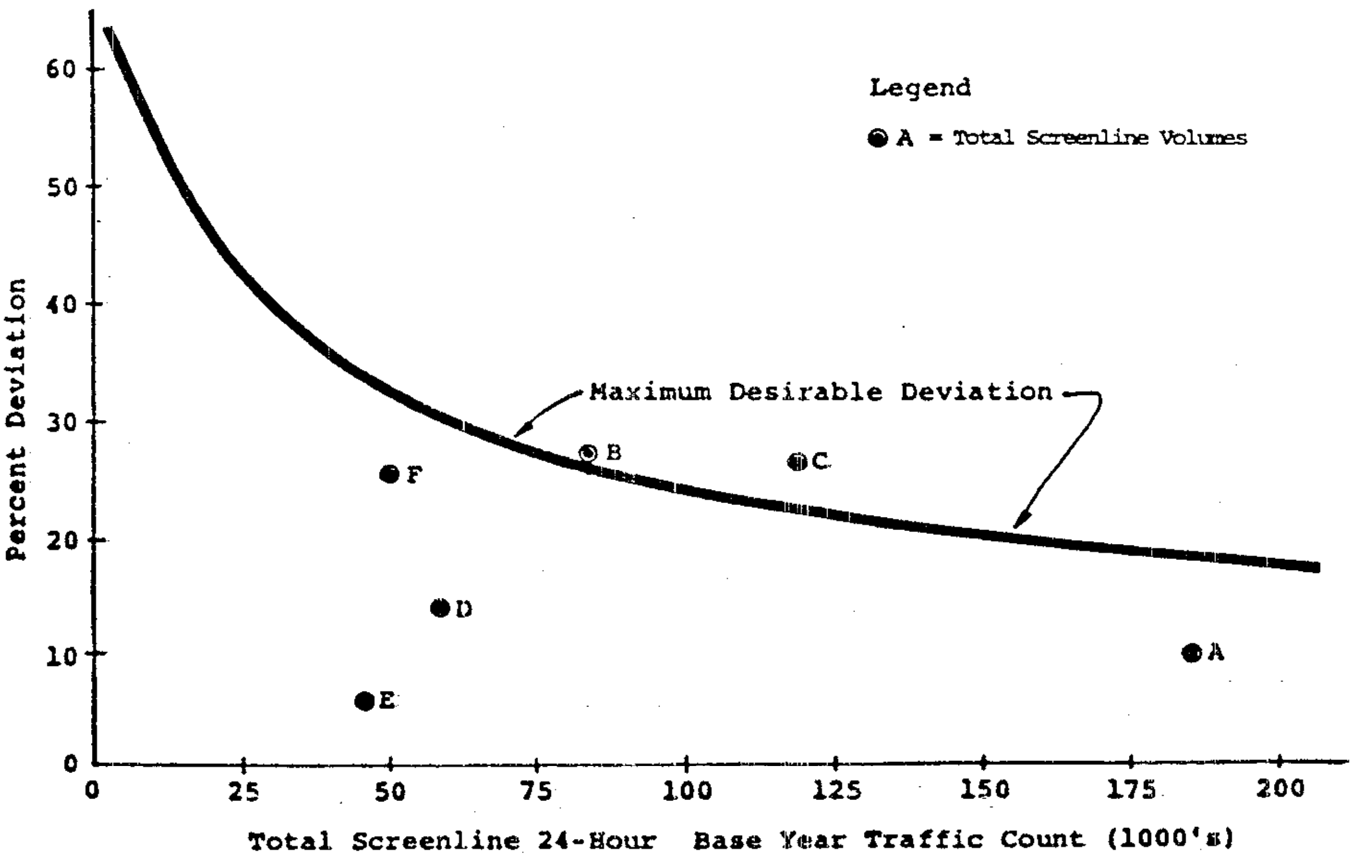
Time-of-day distributions by trip purpose are presented in Figure 3-10. The stratification of link volumes by hour of the day as a post-process to trip assignment is commonly used to estimate emissions.

Time-of-day distributions can be estimated at various stages in the four-step travel demand process (see Figure 3-11 in Section 3.8): prior to trip generation, trip rates are stratefied by time period and purpose; following mode choice, peaking factors are applied by purpose and mode for each time period, and following trip assignment, link volumes are stratified by hour of the day. The most common method to estimate the time-of-day distribution in regional travel models is to apply a set of peaking factors to the trips by purpose and mode estimated from actual data. The peaking factors indicate the proportion of trips in a particular time period that are destined to (or away from) the trip attractors. Peaking factors are often developed for the A.M. and P.M. peak-periods (or peak-hours) and the remainder of the daily trip table is allocated to the off-peak period.

Some models assume that the home-based-work purpose represents the peak-period trips and all other trip purposes represent the off-peak period. This assumption may be reasonable for the mode choice model, but may not be reasonable for trip assignment. Regional travel demand models have in the past emphasized the peak-period for planning purposes, but further accuracy in time-of-day forecasts are required for emissions inventories.



Maximum Desirable Error for Link Volumes



Maximum Desirable Deviation in Total Screenline Volumes

Figure 3-9

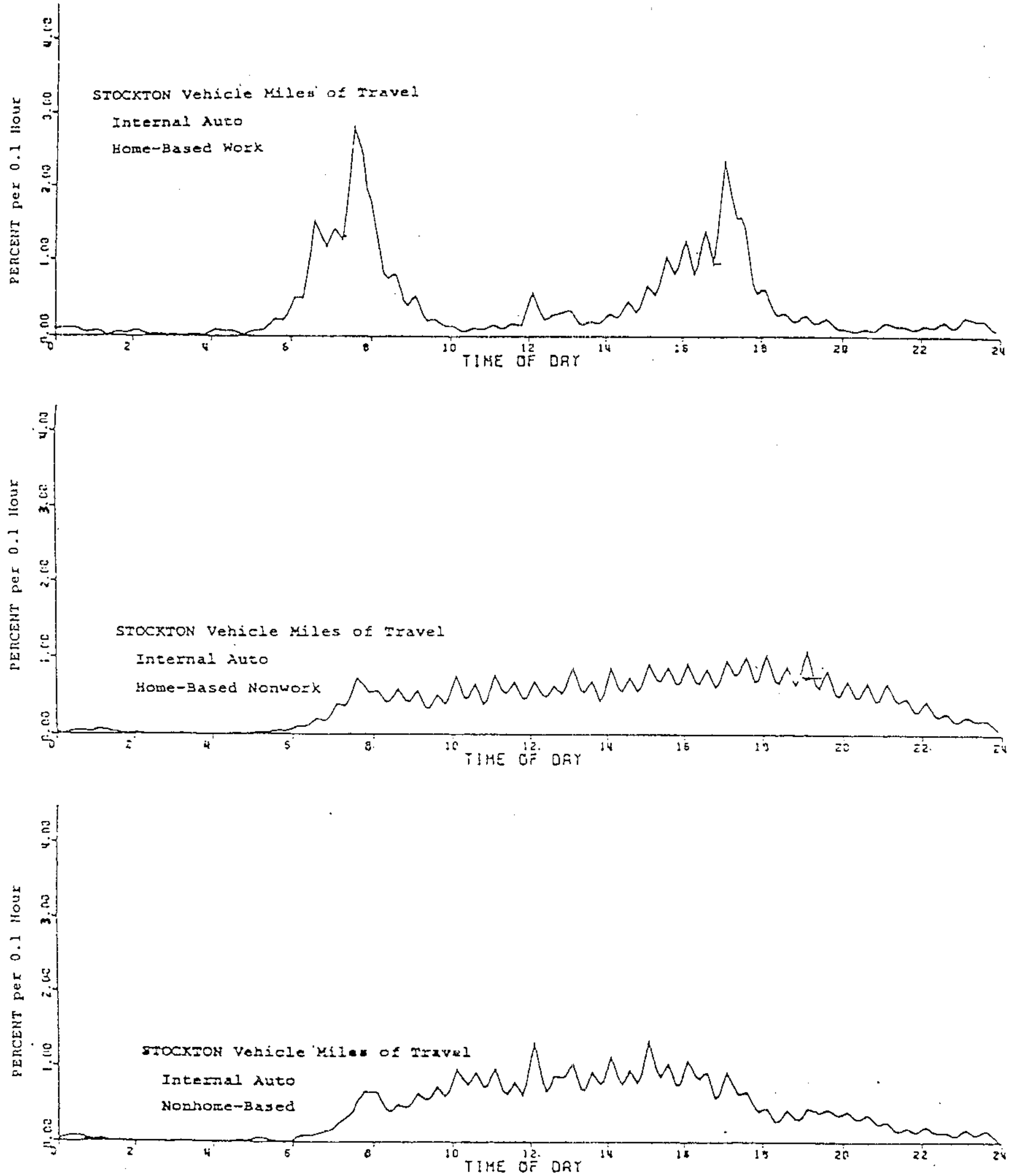
3.7 FORECASTS

The complexity of travel demand models is often limited by the ability to accurately forecast the data and assumptions defined in the models. Although the basic structure of the four-step modeling process has changed little in the past twenty years, there have been some developments over time to incorporate more complex traveler behavior and system performance characteristics to capture the causal relationships behind shifts in travel. Both the calibration and validation efforts involved in each of the four models can verify the ability to estimate travel demand from travel behavior and system characteristics. Typically, each of the four models in the travel demand forecasting process assumes that the parameters and coefficients estimated through model calibration do not change over time. The input socio-economic and network characteristics tested during model validation will change over time and are developed for each model application year.

Forecasts for the trip generation model require estimates of future year socio-economic data (households and employment, stratified by those categories identified in the trip generation model). If special generators were used in the base model, estimates of future special generator trips should be incorporated into the forecast year model. If internal-external and external-internal trips were based on estimates of traffic at the external station, these need to be estimated for the future year. Typically, special generator and external travel are estimated by growth factors for the forecast year.

The gravity model application of the trip distribution model assumes that the friction factors and K-factors do not change over time. This assumption is based on the use of these factors to capture the travel behavior not otherwise accounted for in the model. Because the behavior producing these factors is not well defined, the assumption that the factors will not change over time is suspect. The production and attraction trip ends are forecasted from the trip generation model and the zone-to-zone impedances are estimated from the system characteristics for the forecast year.

The mode-choice model contains coefficients that explain the relationships between travel behavior and mode choice. The model-calibrated coefficients remain constant over time. The travel time, or impedance, values are derived from forecasted changes to the highway and transit systems. Costs are input in base year dollars and only change over time if the forecasts differ from the increase due to inflation.



Source: *An Analysis of Urban Area Travel by Time of Day*, U.S. Department of Transportation, Federal Highway Administration, 1972.

Figure 3-10
Time-of-Day Distribution by Trip Purpose

Assessments of the forecasting performance of travel demand forecasting models have indicated that the errors occurring are dominated by poor forecasting of the input variables (Bates, Dasgupta, 1990). Additional difficulties with forecasting performance are the assumptions in trip distribution and trip assignment, that are not directly related to travel behavior (such as K-factors and path-building algorithms) and are difficult to forecast.

3.8 FEEDBACK MECHANISMS

There are many assumptions in the four-step travel demand forecasting process that concern the impedance of a trip. The impedance of a trip is a function of the travel time and cost from the origin to the destination. The impedance is derived from the transportation system characteristics. Feedback mechanisms represent the equilibration of impedance at one or more steps in the modeling process, as shown in Figure 3-11. Much of the discussion on feedback mechanisms of impedance leads to a need for further research for the benefits of incorporating feedback mechanisms versus the costs associated with the equilibration required in the modeling process. A significant portion of the costs involved will result from the need to re-calibrate each model, after incorporation of feedback loops. Several discussions on feedback and equilibration in travel demand forecasting can be found in the "Review of Transportation Planning Textbooks & Other Material on Feedback & Equilibration" (Purvis, November 19, 1991). The first assumption occurs in the development of land use data. Land use forecasts are frequently developed with the assumption that transportation system characteristics will not impact the land use. Land use will be developed for a forecast year and assumed to be constant across various transportation system alternatives. Sometimes, low, medium and high growth scenarios are developed, but again, are often not impacted by the transportation system alternatives. This assumption is based upon the need to produce objective forecasts of land use data and the few practical applications into the behavioral theory of how land use is impacted by transportation system characteristics.

Most trip generation models assume that the decision to make a trip is made independent of transportation system characteristics. This assumption has been identified as further research for the trip generation model, but has not been incorporated into state-of-the-practice models.

The trip distribution model is the first of the four-step process to incorporate impedance values as a variable. The current state-of-practice models use uncongested impedances to determine the destination choice of a trip. Some models estimate congested impedances as a function of facility type and area type as a shortcut to using modeled congested impedances. Current state-of-the-art models complete the four-step process and feedback the congested impedances to trip distribution. Some models equilibrate this feedback loop until the congested impedances used in trip distribution match the congested impedances output from trip assignment.

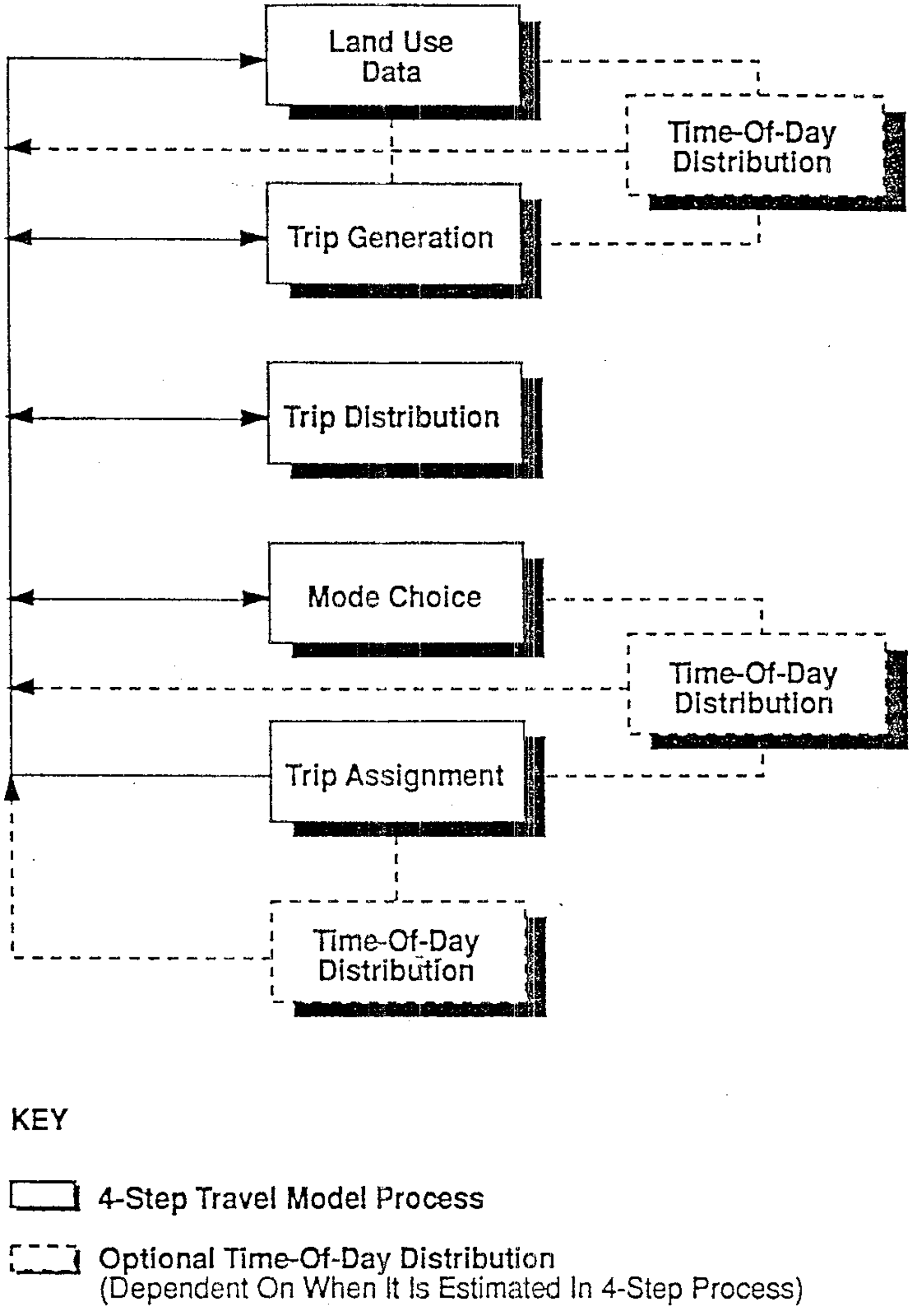


Figure 3-11
Feedback Mechanisms to Equilibrate Impedance

Congestion has been identified as having a significant impact on mode choice, thus state-of-the-practice mode choice models have incorporated feedback loops of the congested impedances to not only the mode choice models, but also the estimate of transit impedance where it is effected by highway congestion. State-of-the-art models have equilibrated this feedback loop.
(Purvis, Nov. 19, 1991)

Trip assignment is the only step in the modeling process in which feedback loops and the equilibration of congested impedances is incorporated into state-of-the-practice models. The capacity restraint function, depicted by the BPR equation or the exponential equation, is the technique used to estimate delay from congestion and iterate to affect path choice on the basis of this delay.

3.9 MODEL APPLICATIONS

3.9.1 Analysis of Transportation Control Measures

The increasing concern about air quality has resulted in increasing use of travel demand forecasting models in the evaluation of the potential impact of transportation control measures (TCM). TCMs include a wide variety of measures designed to reduce vehicular travel, including rideshare promotion, parking pricing, increased transit service, alternative work schedules, and bicycle and pedestrian facilities. The impacts of TCMs are normally assessed on the basis of changes in vehicle miles of travel, trips, or changes in pollutant emissions. Travel demand models would readily produce the impacts in the desired form, but most travel demand models are relatively insensitive to the variables that are affected by the TCM's, such as trip cost by alternative mode, travel comfort, or awareness of alternatives. An analysis of TCM's can often use the data contained in the travel demand model, even when the travel demand model itself is not capable of forecasting TCM impacts. In such applications, the travel demand model supplies baseline travel characteristics, but the actual TCM impact is predicted in a post-process model that is sensitive to the relevant influences.

TCM analysis should predict TCM impact on the basis of either relevant econometric relationships based on travel behavior theory or on empirical evidence of effectiveness where methods have been tried before. It should be clear whether empirical evidence represents average effectiveness or maximum feasible effectiveness. The TCM analysis should take explicit account of the cumulative impact of multiple TCM measures and how that may differ from the sum of the individual impacts. When TCM's are analyzed as a post-process, care should be taken to ensure that TCM measures already incorporated in the travel demand model are not double counted.

3.9.2 Congestion Management

The Congestion Management Program has become a driving force for many regional transportation agencies to develop or update their transportation model. While the CMP legislation does not specifically require a travel demand model, there are certain requirements that imply the need for a model. The land use analysis program, for instance, requires a "program to analyze the impacts of land use decisions made by local jurisdictions on regional transportation systems...". The legislation continues to state "the agency... shall develop a uniform database on traffic impacts for use in a countywide transportation computer model and shall approve transportation computer models of specific areas within the county that will be used by local jurisdictions to determine the quantitative impacts of development on the circulation system that are based on the countywide model and standardized modeling assumptions and conventions". (Section 65089, Government Code)

It is this legislation, in combination with the Federal Clean Air Act Amendments (1990) and the California Clean Air Act (1988) that has prompted a critical look at travel demand forecasting models. Many people apply travel demand forecasting models without a clear understanding of the strengths and weaknesses. This often results in a lack of understanding of the appropriate applications of the model. For instance, transportation modelers do not believe that regional transportation models are accurate enough for intersection capacity analysis, but can be used in an incremental analysis to forecast level-of-service for intersections. Subregional models are often used for intersection capacity analysis; these models are required, by legislation, to be consistent with the regional model. This requirement will serve to determine an equivalence between one forecast and another, and should improve the decision-making process by providing results based upon similar assumptions. In theory, this is a strength of the legislation, but in practice, it will take some time to provide consistency between travel demand forecasting models.

The intent of the CMP is to reduce congestion on the highway network by coordinating land use, air quality and transportation planning. The travel demand model is the link between these areas, and will provide the necessary connection from one arena to another. The models are currently being applied to analyze congestion on highway and transit networks and as input data to emissions inventories.

3.10 REGIONAL AND SUBREGIONAL MODELING RELATIONSHIP

The CMP legislation requires consistency between regional and subregional (or local) models. Consistency should be determined by comparisons of the input data, model assumptions and results. The most effective way to achieve consistency between these models is to directly connect the input data sources and the parameters and assumptions. Some regional models are developed to incorporate existing local area models. Subregional models can be developed directly from regional model databases and follow similar modeling assumptions or apply regional modeling results where appropriate, such as to capture major mode split impacts of large transportation projects. Subregional models have the advantage of closer attention to detail and more accurate input data, while regional models have the advantage of capturing regional travel behaviors that might be difficult to model in a smaller area. Both models stand to gain from incorporating parts of other models, or using the other models as a reasonableness check where validation data is scarce.

3.11 MODEL DOCUMENTATION

Model documentation is a step towards improving the understanding and usefulness of travel demand forecasting models. If the model documentation is too brief to be useful, or it is not updated with changes to the model, then it will not be as useful to modelers. Model documentation may contain many variations of information, and are difficult to compare or contrast without guidelines. The following is a list of suggested topics for model documentation:

- Description of modeled area and network coverage
- Tabulation of land use or socioeconomic data for all years modeled
- Description and summaries of all variables in the networks
- Source and coverage of traffic counts used in modeling
- Description of the trip generation model by trip purpose
- Identification of special generator and external trips input to trip generation
- Summary of trip generation results (productions and attractions by purpose by year)
- Description of the trip distribution model by trip purpose
- Description of the source and form of friction factors used by trip purpose
- Description of the impedance measures used in trip distribution, including intrazonal and terminal times
- Identification of K-Factors and their derivation
- Summary of trip distribution results (total and intrazonal trips and average trip length by trip purpose)
- Description of the mode choice model by trip purpose
- Description of the variables (and units) used in the mode choice model
- Summary of the mode choice results (district to district trips by purpose by mode)
- Identification of the source and value of inter-regional trips
- Description, if applicable, of the peak hour models
- Description of the trip assignment model
- Description of the impedance measures used in trip assignment
- Identification of the volume-delay and path-building algorithms applied in trip assignment
- Summary of the trip assignment results (VMT, VHT, delay and average speed)
- Identification of model validation tests and results for each model stage.

l(4315/CHAP3)

CHAPTER 4

EMISSION INVENTORY NEEDS

CHAPTER 4: EMISSION INVENTORY NEEDS

4.1. OVERVIEW

This chapter describes the travel activity data required for air pollutant emission inventory needs. The chapter identifies which elements of the travel activity data are derived from regional travel models and provides guidelines for how those elements should be produced. The chapter also describes sources of supplemental data that aid in emission inventory analysis and methods for validating the travel activity data used in the analysis.

4.1.1 - Historical Development of Emission Estimation Practice

The Federal Clean Air Act of 1970 produced a legislative mandate to improve air quality in certain metropolitan areas by controlling on-road motor vehicle emissions. The 1970 Clean Air Act initiated a linkage between travel forecasting and planning and air quality analysis that has continued for almost twenty years. Developments in the last few years, however, have suggested that the integration of travel forecasting and air quality analysis can be performed much more accurately than has been the practice.

The 1970 Clean Air Act established strict emission standards for all auto makers for cars sold in the United States. As a framework for determining compliance with the standard, the U.S. Environmental Protection Agency (EPA) developed the Federal Test Procedure (FTP), which contained a specific driving cycle -pattern of start, accelerations, cruising, decelerations, and idles over a specified terrain. Vehicles could then be tested to determine whether they were within the threshold limit of emissions over this FTP driving cycle, the average speed for which was 19.6 miles per hour (Horowitz, 1982). The use of the FTP, however, went far beyond its original intended application. A table of vehicle emission rates by speed was developed by interpolating between the emissions from the FTP cycle and several other cycles with different average speeds. The tables developed by EPA were then based on the emissions produced for each specific average speed measured over the test cycle (Guensler, et.al. 1991). As a result, the emissions did not reflect the rate produced at a continuous cruise at the specified speed but were instead a combination of starts, accelerations, decelerations, cruising and idling over a cycle that averaged the speed indicated.

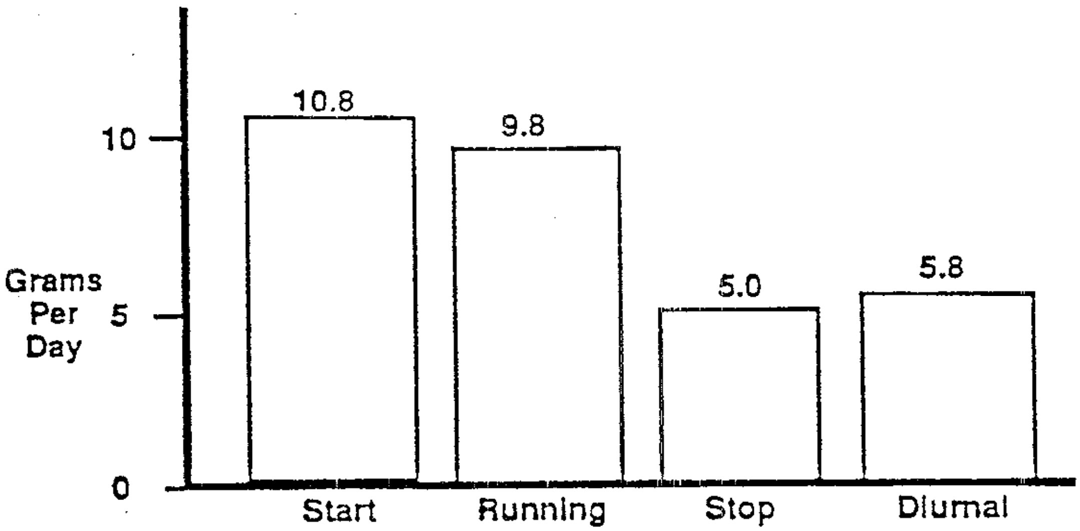
With the development of speed- and vehicle-type-specific emission rates, the next step was the application of these emission rates to the link-specific volumes and speeds produced by regional travel forecasting models common throughout metropolitan areas in the United States. Although the approach provided a previously unavailable method for estimating emissions from travel forecasts, it focused exclusively on VMT and average link speed as determinants of emission rates.

4.1.2 - Sensitivity of Emissions to Travel Characteristics

Despite the extensive use of the FTP driving cycle and speed-based emission rates produced from it, research continued at EPA and state organizations such as the California Air Resource Board (CARB) to identify the more specific determinants of variation in emission rates. The result of this research has been a fairly clear determination that vehicle emissions can be identified in at least four specific categories: trip start emissions, (cold start or hot start depending upon the period for which the vehicle has been turned off), hot stabilized running emissions (exhaust and evaporative), hot soak evaporative trip end emissions and diurnal emissions (hydrocarbon emissions from evaporation that are essentially unrelated to the amount the vehicle is driven).

Although the research is continuing as to the degree to which each of the types of emissions contribute to the overall motor vehicle emissions, an indication of the magnitude of each is provided in Figure 4-1. This graph provides an estimate of the pollutant emissions of hydrocarbon (reactive organic gases or non-methane hydrocarbons) that would occur in 1990 from a 20 mile round trip by a light duty automobile[1] at roughly 75 degrees at an average operating speed of 40 mph. The estimate of these emission components was based on factors derived from CARB's EMFAC7E model. The trip would produce a total of approximately 31.4 grams of hydrocarbon, however, only about one third of the emissions are associated with VMT from the trip. Fifty percent of the emissions result from the trip being made -- this is a combination of the trip start emissions and the evaporative hot soak emissions that occur at the trip end. A final one sixth of the emissions, referred to as the diurnal emissions, occur as a result of evaporation of fuel from the gasoline tank and occur whether the vehicle is driven or not. This calculation certainly demonstrates the importance of including trip starts and ends in emission estimation as well as VMT and operating speed.

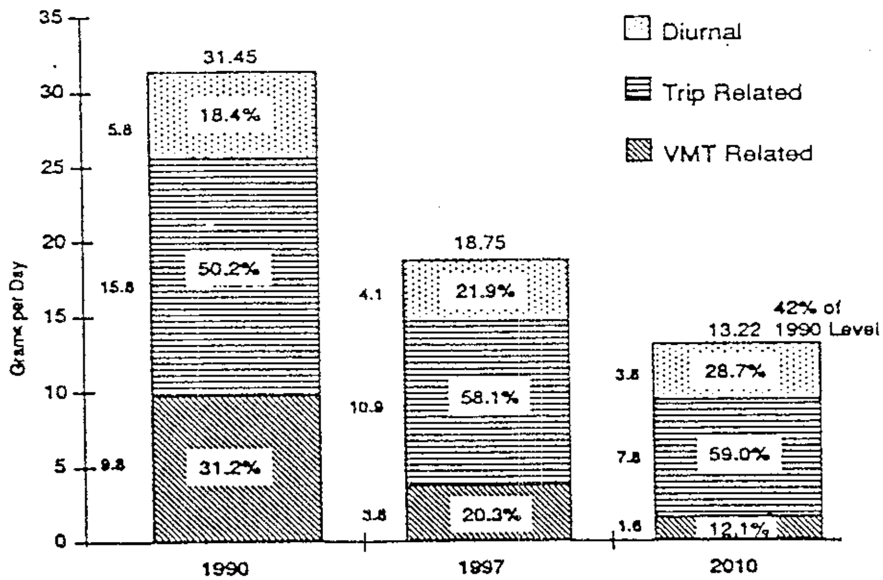
[1] A composite of the light duty automobiles on the road in 1990.



Based on a 20-Mile Round Trip for a Light Duty Automobile in 1990 at an Average Speed of 40 MPH

Figure 4-1

Hydrocarbon Emissions by Type for Prototypical Trip.



Based on a 20-Mile Round Trip for a Light Duty Automobile at an Average Speed of 40 MPH

Figure 4-2

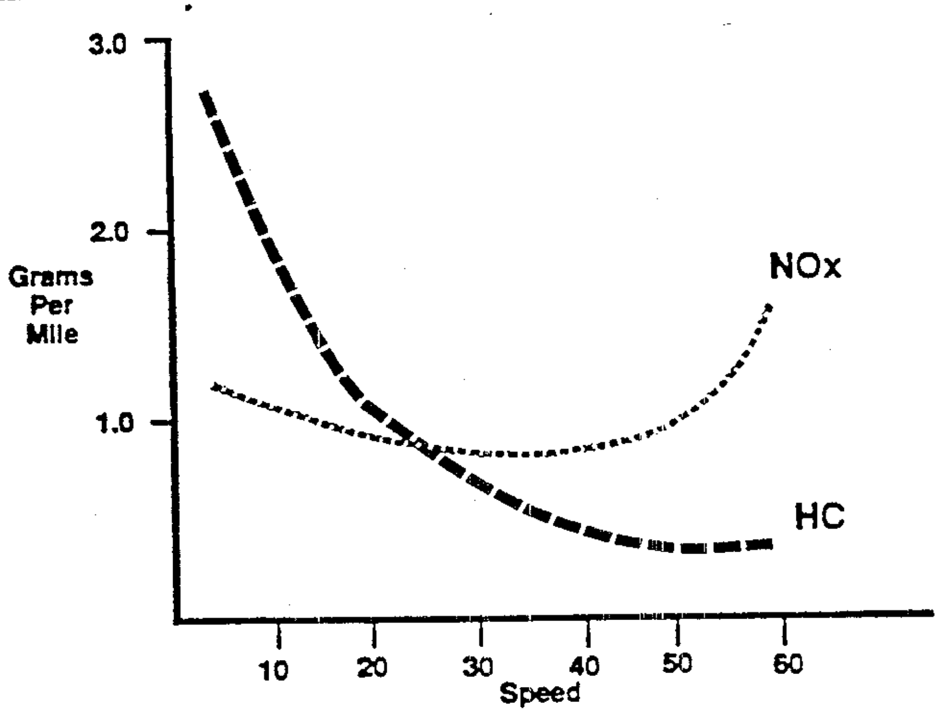
Expected Change in Hydrocarbon Emissions Over Time for Prototypical Trip

Figure 4-2 provides a similar breakdown between VMT-related, trip-related and diurnal emissions for the example trip in Figure 4-1 for 1990 and for the predicted emission rates in 1997 and 2010. The importance of VMT as a determinant of hydrocarbon emissions decreases over time. By 2010, the VMT portion of the emissions for this prototypical trip would be only about one eighth of the total.

Research by EPA and CARB has established that a significant relationship does exist between travel speed and emission rates after controlling for trip-start, trip-end and diurnal emissions. Although the speed-specific rates do still include effects of acceleration, deceleration, cruise and idling, Figure 4-3 provides an approximate mapping of the relationship between emissions for hydrocarbon and NOx and speed. Carbon monoxide emissions are significantly higher on a grams-per-mile basis than hydrocarbons but follow a similar pattern with respect to speed. Figure 4-3 indicates that at least within certain ranges of speeds, emission rates for all three primary pollutants are sensitive to speeds. It is also significant that the relationship for all three pollutants is nonlinear and concave in shape. Research now underway will determine the extent to which the speed sensitivity is a function of the number of acceleration episodes implicit in a particular speed and the extent to which the emission rate is sensitive to the cruise speed itself. Some initial research suggest that most of the variation in rates across speeds are explained by the presence of acceleration periods and that very little variability exists across most normal driving ranges of cruise speed.

The California emissions rate model, EMFAC7E, produces rates in grams-per-hour by dividing by the speed (in miles-per-hour). The rates can be converted to a grams-per-mile basis as illustrated in Figure4-3 but the relationship is undefined at a spread of zero. Emission rates on a grams-per-hour basis are relatively a fairly constant across speeds which has led many analyst in the industry to focus on the use of grams-per-hour based rates.

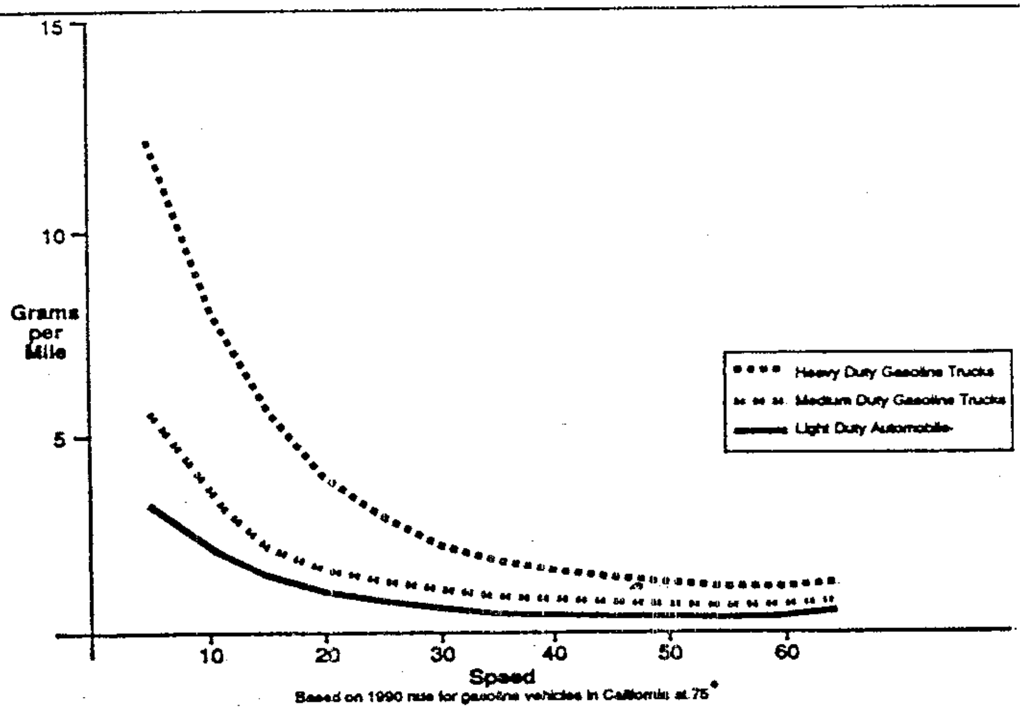
Research on emission rates long ago clearly established that rates vary significantly by vehicle type. The relationship between emission rates and vehicle type is clearly demonstrated by the graphic in Figure 4-4. This graph compares emission rates across three vehicle types: light duty automobiles, medium duty gasoline trucks and heavy duty gasoline trucks. The figure demonstrates that heavier vehicles have higher emission rates at all speeds but that heavier vehicles are also more sensitive to speed. A final area of sensitivity necessary in air quality modeling is the time that emissions occur. This is important in two respects: the ambient temperature (at a specific hour of the day) under which a vehicle has been started will affect the start emission and the time at which emissions are produced will affect the maximum concentrations and location of pollutants.



Based on 1990 Rate for Light Duty Automobile in the Bay Area of California

Figure 4-3

Relationship of Emission Rate to Speed



Based on 1990 rate for gasoline vehicles in California at 75°

Figure 4-4

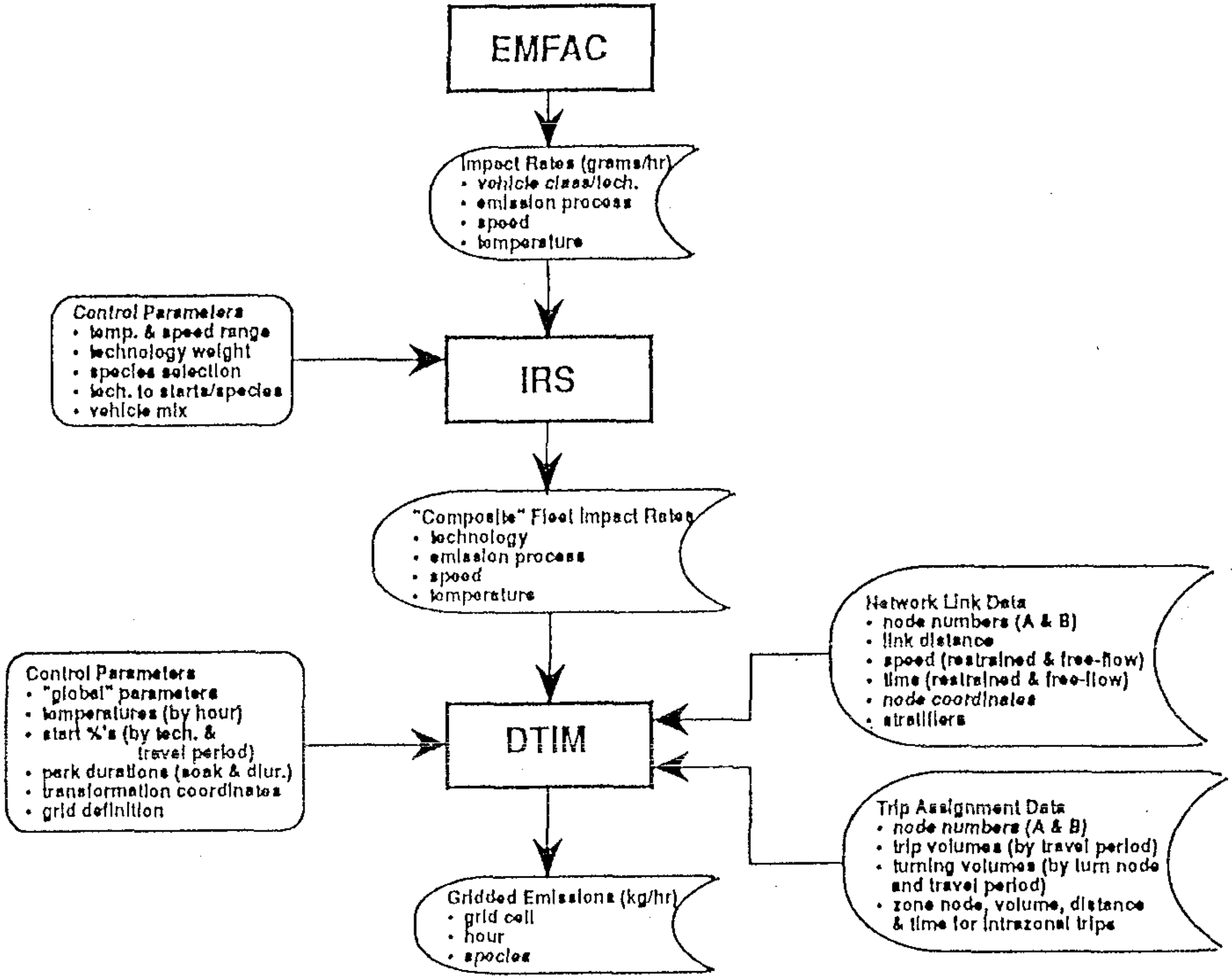
Relationship of Hydrocarbon Emission Rate to Speed by Vehicle Type

4.1.3 - California's Direct Travel Impact Model

These concerns about the sensitivity of pollutant emissions to trip starts, total vehicles (diurnal emissions), operating speeds, vehicle type and time of emissions all suggested that the previously common practice of basing emission forecast on only daily VMT and average operating speeds could produce highly inaccurate results. Fortunately new data and computing capabilities have made significantly more accurate forecasting of motor vehicle emissions possible. Certainly the disaggregation of emission rates into more explanatory component parts (cold start, hot start, running hot stabilize, hot soak evaporative, and diurnal) has significantly increased the ability to predict the quantity, timing and location of pollutant emissions using regional travel models. The Direct Travel Impact Model (DTIM) developed by the California Department of Transportation (Seitz, 1989a and 1989b) has provided the capability to use the output of a regional travel model in an emissions inventory with sensitivity to variations in VMT, number of trips, park duration, temperature, vehicle type mix and speeds. An overview of the DTIM model and its function in emissions estimation is provided graphically in Figure 4-5.

DTIM couples a set of emission impact rates produced by ARB's EMFAC/IRS model with transportation model data and ambient temperature data to compute emissions by square grid cell and hour. Running exhaust emissions are computed for each individual roadway link in the input network file as a function of the average travel time[1] (or speed) on the link. From each link's coordinates (X,Y) the emissions are spatially allocated into grid cells. Starting exhaust emissions are estimated by applying starting impact rates to trip starts compiled by time of day and traffic analysis zone. Evaporative (soak and diurnal) emissions are computed similar to starting emissions except average parking durations are required in addition to the number of "parks" by time of day.

[1]DTIM applies emission rates on a grams-per-hour basis for a specific speed to the estimated travel time (vehicle hours of travel) on the link.



Source: Sierra Research for "Overview of the Travel and Emissions Estimation Procedures for the San Joaquin Valley Emission Inventory," JHK & Associates and Sierra Research, 1991.

Figure 4-5
Detailed Flow Chart for Emission Estimation Procedures

The model is typically run by taking travel estimates for three daily periods: AM peak, PM peak and off-peak to the emission impact rates. Individual hourly variation in emissions within either of these periods is then based on input hourly temperature variations and trip starts or "parks" data (see INPUTS/Control Parameters).

Key Assumptions:

- Vehicle starting emissions are assumed to occur as cold or hot starts based on the duration the vehicle is parked before starting as follows:

	Hot	Cold
Catalyst vehicles	1 hour or less	over 1 hour
Non-catalyst vehicles	4 hours or less	over 4 hours

- Emissions within the grid domain are based on a single diurnal temperature profile.

- Hot soak evaporative emission rates are a function of soak (park) times (normalized for one hour) as follows:

Minutes (of park)	0	30	60	120	>120
Cumulative rate (%)	0	70	100	130	130

Inputs:

- Control Parameters

  - o "global" parameters (calendar year, altitude, pollutants, speed and temperature range, etc.)
  - o transformation coordinates (to translate network coordinates to grid coordinates)
  - o grid definition (origin, size and number of cells)
  - o ambient temperatures (by hour, single site)
  - o starts (% of trips which are hot and cold starts by technology and travel period)
  - o parks (% of trips which are parks (not starts) and average park duration by travel period)

- "Composite" Impacts Rates - Emission impacts rates by technology, emissions process, speed and temperature produced by IRS program.

- Network Link Data - Network link data from a transportation planning model. Each record describes a link in the network. The link description incudes:
  - o node numbers (identifying numbers for the link endpoints)
  - o link distance
  - o link speed (peak and off-peak)
  - o link travel time (peak and off-peak)
  - o link type (freeway or other)
  - o link node (endpoint) coordinates

  Running exhaust emissions are computed by applying impact rates specified by the link speed individually to each link in the network. (Link volumes are given in the Trip Assignment file described below.) This process can be run by hour and the emissions are then allocated into grid cells.

- Trip Assignment Data - Trip assignment data is input to DTIM from a single file containing three types of records: Profile (Link) Volume records, Intrazonal volume records and Terminal (Trip End) Records. Each is described in detail below.

- o Profile record - Contains vehicle volumes by travel period (e.g., peak and off-peak) for each of the network links (identified by node numbers). Each record represents an individual link.
- o Intrazonal record - Transportation Planning models estimates of vehicle volumes throughout an urban area consist of an additional component of travel called "intrazonal". A roadway system is modeled as a number of irregularly shaped zones (traffic analysis zones), each of which contains a number of individual links, representing the roadways in the zone. From socio-economic data, trips <u>between</u> each of the zones are developed and volumes are assigned to links between each zone pair based on the "resistance" assumptions in the network. Short trips which occur <u>within</u> each individual zone are estimated separately and intrazonal volumes from these trips are assigned to each zone. The intrazonal record contains intrazonal volume for each travel period and the estimated average time, distance and speed of these trips. Each record represents a single zone.
- o Terminal record - Contains trips (productions and attractions) by travel period for each zone pair in the roadway system.

  The formats of Network Link file records and each of the Trip Assignment file records are similar to those produced by transportation planning models. However, there are a number of transportation models in use and the output record structure varies for many of them.

The basic guidelines for emission inventory analysis in California have been established by the statewide use of DTIM. The methodology contained in DTIM represents the most sophisticated approach to using regional travel model output to produce emission inventory data for on-road motor vehicle activity. New software is now being developed to apply the same concepts contained in DTIM, but the DTIM model remains the standard for emission inventory development. Because of its sophistication and its widespread use, the input requirements of DTIM define the acceptable level of practice for California. The guidelines in this chapter generally suggest the acceptable level of practice for development of the DTIM inputs.

4.2 TRIP VOLUMES BY PURPOSE AND TIME PERIOD

<u>4.2.1 - Trip Purpose Categories</u>

Accurate prediction of the air quality impacts of on-road motor vehicle activity is critically dependent on accurate prediction of trip volume by purpose and by time period. As indicated in the overview section to this chapter, the quantity of pollutant emissions is highly dependent on the number of trips as well as the number of miles traveled. But also important determinants are the speed at which travel occurs, the temperature at which the travel occurs, and characteristics of the vehicle being operated. Although these detail characteristics of the travel are generally not direct outputs of the regional model (speed is estimated on an aggregate basis for certain time periods or on a daily basis), they can be approximated in post-processing steps on the basis of trip purpose. For that reason, the prediction of trip volume by trip purpose in the regional modeling process is important to the determination of pollutant emissions.

If trip purpose is used to estimate time-of-day and vehicle type distribution, at least three trip purposes should be used: home-based work (HBW), home-based non-work (HBNW), and non home-based (NHB).

This minimum trip purpose differentiation separates those trips for which the total number is based on number of households in the region (HBW and HBNW) from those trips which are not directly related to number of households (NHB). The second category is often used to include commercial travel, tourist travel, and other travel not reflected in resident-based home interview surveys. As a result, the trip volume in this category is often adjusted in calibrating a regional model to produce an appropriate number of total trips. The separation of work from non-work trips out of the total home-based trips provides significant information about the timing of trips and about the length of stay at the trip destination (the attraction end of the trip). Further differentiation of home-based non-work trips and non-home-based into subcategories can significantly improve on representation of travel behavior and is recommended for advanced practice. This improvement, however, is generally more significant in the estimation of other travel characteristics such as trip length, trip destination, and mode choice than in the estimation of time-of-day or vehicle-type distribution.

4.2.2 - Time Period Definitions

Most regional travel models that provide average annual daily forecasts normally also produce either one or two peak-period forecasts designed to represent the travel that occurs under the heaviest flow conditions during the day. In some cases, a period may represent a single peak hour or it may represent a two- or three-hour period.

Time period definition should be designed to capture homogeneous characteristics of travel such as congestion, mix of trip purpose, and travel speeds. Whenever congestion has a significant impact on peak period speeds, peak periods should be modeled separately.

Time period definition should be chosen to distinguish the travel occurring under congested conditions from the travel occurring under free flow or uncongested conditions. Because emission rates are so critically dependent on speed (using existing emission rates), the most important criteria for definition of time periods for emission estimation is probably homogeneity with respect to speeds. The DTIM program allows for two different speeds to be specified for each link in the system -- a peak-period speed and an off-peak period speed. While this certainly does not capture all of the variation in speed and will result in some biasing of emission estimates, it is a significant improvement over an assumption of constant speed throughout the day.

4.2.3 - Travel with External Trip Ends

The treatment of trips into, out of, or through a region introduces additional complexity into the estimation of emissions. The normal practice in regional modeling is to create external zones at the periphery of the region to represent the origin or destination of these trips. The total volume into or out of these zones can be estimated for a baseline year using observed traffic counts. The volume for a future forecast year is estimated using a variety of projection techniques, the most common being to project past growth rates on the roadway observed. Allocation of travel to and from these zones to time periods becomes complex for any trips with the production end in the external zone. For these trips, the trip purpose is not known and so a supplemental, empirically-based method for allocating the trips to a time period must be used. This can be based on the time-of-day distribution for the traffic count used to set the total volume of trips out of the zone.

4.2.4 - Special Forecasts

By far the most common practice in California is to calibrate regional forecasting models for average annual weekday travel. Special accommodation must therefore be made if a model is to be used to represent a particular season of the year (the most serious ozone violations tend to occur during the hottest part of the summer) or for weekend days.

Whenever the model is used to forecast for a specific season, corrections based on observed seasonal variation should be made to account for the difference between average annual conditions and the particular season being evaluated.

If the forecast is for a typical weekday, the correction may be quite minor because the same trip purposes might apply. Forecasts for weekend days, however, should, whenever possible, be based on a model of weekend travel. Much of the travel that occurs on an average weekday, such as work and school trips, do not occur in as great a number on weekend days. In addition, there is a significant amount of weekend recreational travel that is not included in weekday models.

In general, when weekend forecasts are made, forecasts should rely on observed weekend data, and the use of trip purpose from weekday forecasts should be minimized.

Vehicle emissions can also be affected significantly by the occurrence of special events that would affect either the total volume of travel or the nature of the travel that occurs (timing, speed, vehicle mix, etc.). Special events might be planned events such as fairs, sporting events, etc., or unplanned events such as traffic accidents. Incorporation of the effects of special events is generally beyond the scope and capability of a regional model.

Wherever special events are known to have a significant impact on an emission inventory, external adjustments should be made to the travel activity data to reflect the impacts of the event. This may include adjustment of the number of trips, adjustment of VMT on particular links, adjustment of average operating speeds, adjustment of the time-of-day distribution of travel, or adjustment of vehicle type distribution on a particular link.

4.2.5 - Comprehensive Coverage of Trips

As the use of regional models in emission inventory development increases, the concern about comprehensive coverage of all travel also increases. Most regional models were constructed primarily for the evaluation of transportation infrastructure needs. The main purpose in evaluating the regional models was the accuracy of estimating peak-hour or peak-period volume of major facilities, whether they be roadway or transit facilities. The volumes predicted for future years were then used to determine the appropriate size for the facility in that future year. Under these conditions, exclusion of some trips from the modeling system was not important if those trips did not contribute significantly to the VMT on major facilities during peak periods. For emission estimation, however, comprehensive coverage of all trips is much more important. Because of the significant contribution of emissions from starts, particularly cold starts, a trip can have a significant impact on emissions regardless of the length of the trip.

Because of the significance that they may have in an emission inventory, all trips regardless of time of day, location, or trip length, should be included in a transportation model.

Because of the regional nature of certain pollution problems such as ozone, the exact location where the emissions occurs is of less significance than the quantity of the emissions and in DTIM, emissions are aggregated by grid cell. Emissions occurring on minor or residential roads can contribute equally to ozone formation as emissions occurring on a major freeway. But because of the significant relationship between speed and emission rate, the impact of short trips on minor roads on emissions is generally greater than their impact on VMT or total trips. Most minor streets in urban areas operate with average operating speeds of less than 20 mph because of frequent stops. As a result, this travel is probably the most polluting on a grams-per-mile basis.

The major source of data used in the development of a regional travel model (those developed from regional data not transferred from another region) is a home interview survey. As a result, the regional models are most fully developed for trips made by residents of the region and particularly those trips made to or from the home. Non-home-based trips by residents and trips by non-residents are frequently underrepresented or excluded entirely. This most frequently includes commercial travel, tourist or visitor travel and recreational travel. Although classified as home-based trips, school trips are also frequently underreported or excluded. A special effort should be made to ensure that all of these trip types are included in the travel activity data.

If the regional model output underrepresents or excludes any trip types, supplemental activity data should be provided.

The DTIM model operates on vehicle trip assignments for a regional travel model. As a result, a DTIM-based emission inventory potentially excludes emissions from transit vehicles. This is likely to be a significant factor in major metropolitan areas with a substantial bus fleet.

Where emissions from transit vehicles is likely to be significant, DTIM analysis should be supplemented with travel activity data for transit vehicles.

In areas with park-and-ride facilities, the regional modeling also often ignores the automobile access to the park-and-ride lot. Because a significant percentage of emissions from a trip are associated with the starting of the car, the trips to and from the lot can be significant and should be recognized in an emissions inventory.

Where a significant number of transit or carpool trips use park-and-ride lots, DTIM analysis should be supplemented with activity data on the trips to and from the park-and-ride lots.

4.3 VEHICULAR SPEEDS

4.3.1 - Relationship between Speed and Emission Rate

As indicated in the overview section for this chapter, current emission rates from California Air Resources Board reflect a significant relationship between emissions on a gram-per-mile basis and average operating speed. The U.S. Environmental Protection Agency's model, MOBILE4.1, reflects a similar relationship, although California's EMFAC model goes farther in separating out trip end related emissions from hot stabilized running emissions. Within these speed-dependent emission rates, however, there is considerable uncertainty that arises from the method by which the relationship is developed.

The speed-based emission rates from EMFAC and MOBILE represent an average rate on a grams-per-hour basis over a range of operating modes (accelerating, decelerations, cruise speeds and idles) for which the total time and travel distance reflect the average operating speed that the emission rate represents. The actual emissions that occur for a particular operating speed depend on the specific pattern of operations that occur. The emission that occurs at a constant cruise speed of 30 miles per hour are much lower than the emission that would occur over a series of accelerations and decelerations that produce the same 30-mile per hour average operating speed.

Despite the imprecise nature of current emission rates, specifically the relationship between speed and emission rates, close attention to the speeds is still warranted, while the existing methodology for relating emission rates to speed captures more than just the relationship of speed itself, average operating speed remains a reasonable proxy for the characteristics that influence the emission rates. It is important to recognize, however, that this relationship with speed may be one of only correlation and not direct impact.

4.3.2 - Consistent Use of Speed

To be consistent with the emission rate models, speeds should represent average operating speed over a section of a facility, not the mid-block cruise speed or the speed limit on the facility.

The speed supplied to DTIM should represent the average over the cycle of acceleration, deceleration, cruise, and idles that occur over a reasonably long section of the facility. To the maximum extent practical, the speeds used in the travel modeling steps should be consistent with the speeds used in the emission estimation. However, the travel forecasting steps are generally less sensitive to speed variation than emission estimation and the same level of detail may not be warranted in the travel forecasting model. For this reason, the speeds used in emission estimation may be developed through a post-processing speed/volume/capacity analysis step using data that have greater time-of-day detail than was available from the model system. As a result, the speeds used in emission estimation may not be identical to those used in the modeling steps. There may be sufficient variation for speeds within a peak period to justify hour-by-hour estimate of speeds by link using post-processing steps for emission estimation. Hour-by-hour assignment within the transportation model may not be justified, however, and so separate speeds for emission estimation and for modeling travel behavior might be warranted.

It is also common practice to use free flow speeds for off-peak periods in regions where there is little or no congestion during the off-peak periods. For emission estimation, however, there can be a significant difference between a free flow speed and the slightly lower loaded speed that results even under uncongested conditions. This may be particularly important at the high end range of speeds, at which higher speeds can result in greater emissions.

Given that speed is used as a proxy to represent a variety of travel characteristics that affect emission rate, speed should be estimated for emission estimation purposes in as detailed a manner as is practical and consistent with the definition of speea used in emission rate models.

4.3.3 - Averaging of Speeds

The nonlinearity of the relationship between speed and emission rate introduces a significant concern about the effects of averaging of speeds. Because the relationship is nonlinear and concave in shape, the emission estimate using an average of two speeds will almost always produce a lower value than the sum of the estimates using the two different speeds. While it has been clear for some time that emission rate increases sharply with a decrease in speed at low speeds, there has recently been an increasing amount of evidence that the emission rates for all three of the primary pollutants also increases with speed in higher speeds over 50mph. This research reflects in greater non-linearity in the relationship and argues more strongly against averaging of speeds.

Because of the nonlinearity, averaging of speeds over time periods or across vehicles within the same time period should be minimized.

The evidence of increasing emission rates at high speeds has also focused new attention on the maximum speeds allowed within a model system. While the transportation modeling has not been particularly sensitive to these maximum speeds, emission estimates may be.

The free flow speed on a link should be based on observed free flow speeds under uncongested conditions on the facility and not be constrained to speed limits as the maximum speed.

The nonlinearity of the relationship between speeds and emissions also raises a concern about the treatment of the distribution of speeds within a time period. Current practice is to estimate an average speed for the period using speed/volume/capacity relationships. While these relationships might produce accurate estimates of the average speed on a link, use of the average may cause significant bias in the emission estimates. As the relationship between speed and emissions becomes more clearly defined with current, ongoing research at ARB and EPA, more consideration should be given to use of speed distribution in emission estimation rather than just average speeds. This could be incorporated directly into the emission rates if the emission rates can be more specific to roadway characteristics or level of service. At present, the emission rate for 30 mph is the same for a freeway as it is for an arterial, although the cycle of operating modes would be quite different and therefore the emissions quite different. An average operating speed of 30 mph on a freeway is likely to have far more acceleration and deceleration than 30 mph on an arterial. There is also likely to be significantly greater variation in the individual speeds of vehicles at an average operating speed of 30 mph on a freeway than on an arterial, both of which would directly affect the applicable emission rate.

Figure 4-4 in the overview to this chapter provided an example of how the relationship between speed and emission rates varies by vehicle type. Not only does the emission rate increase with vehicle size at all speed levels, but the emission rate for heavy-duty gasoline trucks is more sensitive to speed than medium-duty gasoline trucks or light-duty automobiles. There is also evidence in traffic engineering literature to indicate that there is variation in the relationship between speed and roadway level of service for different types of vehicles. A methodology that differentiates volume by vehicle type and estimates separate speeds for each vehicle type will therefore produce more accurate estimates of emission rates than a methodology that assumes the same average operating speed for all vehicle types on a link.

4.3.4 - Methods for Validating Speed Estimation

Because of the sensitivity of emission estimates to speed estimates, the validation of an emission inventory methodology should include a validation of the speed estimates provided with the travel activity data. Such a validation, however, is much more difficult than the validation of volumes on links because the speeds represented in the model are average operating speeds over a section of the facility rather than instantaneous speeds at a particular point on the network. True validation of the speed estimates would have to be based on travel time runs over a segment which provide only one estimate of speed per run. Collection of sufficient data for validation of speeds is therefore quite costly and potentially beyond the resources of many regional agencies.

A less accurate but approximate validation of speeds can be provided by the spot checks of speeds at single locations. If measured at a mid-block location, this would generally represent an upper bound on the speed estimated by the model because it does not include the effects of intersection delays on average operating speed. The difference between these mid-block speeds and average operating speeds is most significant on arterials or minor streets where there are frequent stop signs or signals, while on freeways the two may be quite similar if not the same.

> *Whenever possible, validation of the speeds used in emission estimation should be validated using floating car speed estimates over a variety of facility types and operating levels of service; but where resources do not permit this method of validation, spot checks of mid-link speeds should be used.*

4.4 PRE-START AND POST-PARK PARAMETERS

With the awareness of the importance of trip start emissions, trip end emissions, and diurnal emissions, increasing attention has been given to the nature of trip starts and trip ends or parks. Because of the limited treatment of trip starts and parks within regional models, DTIM provides significant supplemental data on start and park characteristics. Regional travel models are generally limited to only the prediction of trip ends by zone by trip purpose. In more sophisticated models, trip ends by purpose are predicted for each time period while simpler models predict trip ends only on a daily basis.

More detailed information than is provided by the regional model is required to determine the timing of each trip start and each trip end (the specific hour of the day) and the duration of the park. As indicated in the overview, the hour in which a start or park occurs is necessary to determine the timing of the pollutant emissions, but also the amount of pollutant emissions. The amount of emissions that occur with a start or a park vary with the ambient temperature, and in many areas of California the temperature can vary significantly over the day. In addition, diurnal emissions (those that occur from evaporation of fuel from the gasoline tank and fuel line) occur predominantly with a rise in temperature; therefore, the location of the diurnal emissions of hydrocarbons will be located where the vehicle was located during the period of rising temperature during the day.

The data necessary for specification of pre-start and post-park characteristics within DTIM consist of survey data on:

- o Distribution of start times and end times by trip purpose
- o Distribution of park duration by trip purpose

The most common source for this data is the home interview survey. With this survey data, traditional regional model output can be supplemented to provide the necessary start and park information to provide a reasonable prediction of the timing, location, and quantity of pollutant emissions that are not VMT related.

Although relating trip start and park characteristics to trip purpose as determined by the regional model is the method used in the current DTIM software, other travel characteristics or characteristics of the model zones, could potentially serve the same function as trip purpose. Start and park characteristics from survey data could be related to zonal land use, development density, area type, or other characteristics of the zone. Developing such relationships from survey data might be useful in situations where a regional model does not predict travel behavior by trip purpose or it may be used as a further refinement of start and park characteristics when trip purpose is used as the main determinant. If zonal characteristics are to be used to relate start and park characteristics to model output, the zonal characteristics for each respondent in the survey that is used to develop the relationship will have to be known. An advantage to using only trip purpose is that all of the information necessary to estimate the relationships are normally contained within a single survey of individual travel behavior, such as a home interview survey.

Regardless of the explanatory variables used to predict start and park characteristics, the methodology used to predict these characteristics as a function of regional travel forecast data should be based on a survey of individual travel behavior.

CHAPTER 5

RESEARCH AND RECOMMENDATIONS

CHAPTER 5: RESEARCH AND RECOMMENDATIONS

5.1 INSTITUTIONAL AND RESOURCE REQUIREMENTS

There are three considerations for institutional and resource requirements that would benefit from additional information, further research and a better understanding of the requirements. The legislative requirements are complex and extensive, requiring effort to learn and understand the benefits and costs of each legislative requirement. The modeling coordination between agencies is required by the legislation, but the interpretation of what constitutes coordination is flexible. Modeling coordination between agencies can maximize the resources available for transportation modeling. The consistency requirement of the legislation will improve the comparison of transportation impacts from one area to another and may improve the reasonableness of individual modeling assumptions.

5.1.1 Legislative Requirements

Each regional agency should understand the implications of the legislative requirements, the areas of the legislation that may change over time, and the overall objective of the legislation. Implementation of the legislative requirements will produce additional understanding of the strengths and weaknesses of the legislation. The weaknesses will provide insight to the areas of the legislation that may change over time. Additional research will be required to implement the changes needed in the legislation and carry through the full intent of the legislation. When complying with the first application of any of the legislative requirements, the regional agencies should consider the overall objective of the legislation, and apply judgement to determine appropriate responses to the specifics of the legislation, recognizing that the legislation may change over time.

Recommendation: Seek clarification of legislative requirements and areas were legislation may change to provide understanding of the legislation.

Congestion Management Programs

The intent of the legislation for congestion management programs was to facilitate joint planning efforts among coordinating agencies involved with land use, transportation, or air quality planning. While the intent of the legislation is a significant step in the right direction for congestion management planning, the short time schedule to complete the legislation caused problems in the implementation and understanding of the legislative requirements. The "Congestion Management Program: Resource Handbook", written in November, 1990, offers guidance to understanding the California Government Codes referencing Congestion Management Programs and lists technical resources available to implement the legislative requirements.

There are a few discrepancies in the CMP legislation that warrant further research. Under the current requirements, local agencies may be responsible for mitigating circulation impacts caused by another agency. The legislation states that the agency responsible for the transportation impacts causing the CMP system to drop below the level-of-service standard will be responsible for mitigating these impacts. If other jurisdictions have projects that contributed to these impacts in that area, but did not cause the CMP system to drop below the level-of-service standard, they are not legislatively responsible for mitigating the impacts. This discrepancy causes an unequal distribution of the costs of mitigating transportation impacts. Many congestion management agencies (CMA's) are investigating a traffic impact fee to distribute the costs of mitigating impacts among all developments that caused the impacts.

The CMP legislation states that a deficiency plan must include "....A list of improvements, programs, or actions, and estimates of costs, that will (i) measurably improve the level-of-service in the system....". This term "measurably improve" is not defined in the legislation and could be interpreted differently by different agencies.

The first application of the level-of-service standard allows for "grandfathering" segments or intersections that are below the established level-of-service standards, and established site-specific level-of-service standards for these facilities. This practice could force resources to be redirected to less congested facilities, by identifying less congested facilities as below the level-of-service standard, when existing facilities have a lower level-of-service, but meet the standards applied by the "grandfathering" clause in the first application of the CMP.

The CMP legislation is unclear regarding the responsibility for monitoring and maintenance of the level-of-service on state facilities. This leaves the decision up to the individual congestion management agency, without any clear guidance as to the coordination between Caltrans and the CMA, or the specific responsibilities for each agency.

There are possible conflicting goals of the CMP and air quality programs, such as policies that promote the management of congestion but increase air pollution. One example is the policy to encourage workers to travel to work during non-peak hours (flex-time), when this policy could discourage the use of public transportation or carpooling for these trips. Flex-time policies can reduce congestion on the system, but will not reduce air pollution because it does not encourage transit or carpooling modes of travel.

Federal Clean Air Act Amendments and California Clean Air Act

The intent of the clean air acts was to achieve clean air in the state of California and in the U.S by requiring air quality agencies to meet the air quality standards specified in the acts. The acts require the Environmental Protection Agency (EPA) and the California Air Resources Board (ARB) to provide guidance in meeting the clean air act requirements. EPA has recently completed the updated "Transportation Air Quality Planning Guidelines," and is still working with DOT to complete conformity guidelines. ARB has completed guidance on the transportation provisions of the California Clean Air Act, and subsequent guidance on the CCAA transportation performance standards. Specific legislative references to transportation and indirect source control can be found in the "Congestion Management Program: Resource Handbook".

The EPA RTP Modeling Checklist asks for a variety of feedback mechanisms and equilibration techniques in travel demand models to reflect impacts from one part of the modeling process to another. Some of these methods are being used in state-of-the-practice models and some of these methods have been tested in state-of-the-art models, but have not been widely tested in model applications. The checklist asks for feedback loops in the transportation model to reflect congestion/travel times in land use distributions. Some land use planners accomplish this feedback by a qualitative evaluation of the impacts of congestion on land use distributions, but it is most often not addressed in a quantitative evaluation. This area requires further research before travel demand models can adequately address feedback loops to land use distributions in practice.

Feedback mechanisms to incorporate the impacts of congestion or travel times on the trip generation model will require modification to most trip generation models in use in California. Some guidance from further research could propose acceptable and advanced methods for incorporating these impacts into trip generation.

Intermodal Surface Transportation Efficiency Act

The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 creates many challenges for the transportation professional. One area of the act that may require additional guidance from the U.S. Department of Transportation is the integration of travel demand forecasting models with the management information systems required by the act.

5.1.2 Modeling Coordination Between Agencies

The purpose for coordination of modeling between agencies is to maximize the resources available to develop and apply travel demand models and to recognize the differences between model applications. The area of this coordination that has received attention directly from the legislative requirements is information sharing among travel model user groups and workshops for specific applications of the travel demand models (such as for the congestion management programs). This type of coordination should provide regularly scheduled interactions between the state agencies and the regional agencies, between the regional agencies and the county agencies and between the county agencies and the city, or local, agencies.

Recommendation: Support the interaction between agencies with travel model users group meetings and one-on-one meetings between agencies.

5.1.3 Consistency Of Modeling Approach

The determination of consistency for models of different government agencies (regional, county, or city) should reflect consistency of the input data, assumptions, and results of the four-step travel demand modeling process. Each regional and county agency should determine the requirements to obtain consistency in these three areas. The guidelines for modeling by regional agencies contained in this document should ensure consistency for regional models, without establishing specific requirements for consistency. The state travel model cannot represent reasonable "urban" model results for regional travel demand models and should not be used as a control for the results, but can be used to compare certain model assumptions with regional models.

Recommendation: Evaluate consistency of the modeling approach by comparing input data, assumptions, and results of the four step travel demand model.

5.2 DATA RESEARCH NEEDS

These research needs are based upon the consultant's experience of where the greatest potential weaknesses are in current travel forecasting techniques, and where the greatest payoffs would occur (in terms of improved travel forecasts) with new research.

5.2.1 Land Use and Socioeconomic Data

What is the best method for stratifying employment (attraction trip end) by income categories?

Present modeling techniques either ignore this issue (due to lack of data), or else use crude proxies (e.g., estimating work-end income based on the income of surrounding *residential* areas). Better information may be available from social security tape files, state income tax, or other sources. The stratification of employment by income categories is desirable.

What kinds of biases are create by using the median income in a zone to "created" a stratification of household income categories?

The median is often used to stratify the percentage of households into low/medium/high income categories for trip generation analysis. Is the improved accuracy offset by the errors or biases in the process to stratify households?

Is auto ownership or household income a better predictor of trip generation? Should household size (number of persons) be included as an additional variable?

Both approaches are widely used in the state, with little consensus on which is better.

How can the land use allocation process be improved?

More sophisticated models use mathematical programming techniques to minimize costs of total firm inputs, although most analysts feel that the results to date are still disappointing. A better understanding of the linkage between transportation supply (new projects) and the spatial distribution of land uses is also needed.

How can the role of accessibility in firm and household location in a region be better understood (possible before/after studies).

Recent court decisions have made it imperative that MPO's include this in their evaluation of RTIP projects, and yet there has been relatively little research in the US on this topic.

What are better approaches to analyzing jobs/housing balance issues?

The congestion management programs mandate consideration of this issue, and yet the gravity model may be too aggregate a tool to effectively deal with this issue (the gravity model is an analog, not a behavioral model, and may not be capable of addressing this issue effectively). Since much new affordable housing is being built at the periphery of metropolitan areas in California, the gravity model may be underpredicting trip lengths and long commutes.

5.2.2 Network/Supply Information

Are computerized GIS systems a cost-effective way to maintain and manage the highway and transit network databases?

Is it desirable to use the network as a database tool to store all traffic data? (counts, pavement conditions, accidents, cost, proposed improvements, etc.)

Are intersection penalties a cost-effective method for improving traffic forecasts? How good are software packages that make turn penalties flow-dependent?

Are there data to develop reliable volume/delay curves for ramp metering?

These could be used to create user-defined delay curves in the assignment step.

5.2.3 Cost Information

Is there a single "best" auto operating cost for use in model?

Most areas use the value (cost/mile) that provides best mode split model calibration, but there is no agreement on whether this should include a share of maintenance or other ownership costs of the vehicle.

How can improved methods of forecasting direct parking costs be developed?

These models need to be sensitive to development density, land values, parking availability/excess time (demand/supply imbalances), and the availability of free/subsidized parking.

5.3 MODEL IMPROVEMENTS

The following identifies areas of travel demand forecasting models that need further research. The differentiation between short term and long term model improvements is a determination of the resources available and the resources required for the improvement, and the overall benefits to the model and may also be dependent upon local agency goals, policies, or purpose for model development.

5.3.1 Modeling Assumptions

The validity of assumptions can be tested or verified by collecting data that would support the assumption or by comparing the assumption to other regional models. The latter is recommended as acceptable practice for all regions. For instance, the auto operating cost per mile should be comparable from one region to another, and even though the gasoline, insurance and maintenance of an automobile can vary, the differences can be reasonably qualified for comparison. These types of comparisons can be facilitated by the modeling coordination groups described in Section 5.1.3.

Recommendation: Compare modeling assumptions to other regional models.

5.3.2 Data Needs for Models

There are two areas where data needs can improve the usefulness and accuracy of the travel demand models. Regional travel models should be developed and updated using survey data sources. Many existing travel models rely on transferred demand models due to limited resources. These models may have biases or assumptions that are not applicable to the region, and are not as useful for capturing travel demand behavior for a specific region. If resources for updating the model are not available, the analysis of the Caltrans Statewide Survey can be used.

The use of database management systems to maintain and update input data for the travel demand models will reduce the errors inherent in managing large datasets of this type and will increase the usefulness of the data for other purposes. Developing interfaces with Geographic Information Systems (GIS) data would increase the flexibility of the level of detail in the model and reduce the duplication of effort in various planning departments.

Recommendation: Use database management and geographic information systems tools to maintain and verify input data.

5.3.3 Four-Step Demand Model Improvements

What variable(s) should be used in trip attraction models?

Most trip attraction models use estimates of employment stratified by industry type or floor area stratified by land use to estimate the trip attraction model. The determination of which variable to use in the model is dependent on the data available to develop the database, the data available to calibrate the model and the data available to validate the model. Often the data available at the local level for the development of the database is floor area stratified by land use, because of inaccuracies by zone of employment-based data. The data available in surveys to calibrate or validate the trip attraction model is typically employment. Floor area is difficult to obtain for this purpose. The amount of stratification for either employment or floor area should reflect the variations in trip attraction rates for the industry types or land use types for each region. A category such as non-retail employment may have large fluctuations in trip rates.

Should transportation system characteristics be incorporated into trip generation models?

Most trip generation models assume that transportation system characteristics, such as speed or capacity, do not significantly affect trip-making behavior. This assumption limits the trip generation model in its ability to capture travel behavior, as well as, in its ability to test changes in the transportation system. The identification of which system characteristics should be incorporated is left for further research.

Should trip generation models incorporate feedback loops for transportation system characteristics?

This will become feasible after trip generation models are modified to include system characteristics. Once they are included in the trip generation model, the argument to include feedback loops is consistent with the argument to include feedback loops to trip distribution and mode choice.

Should the trip distribution model be a choice-based model?

There are many advantages and disadvantages to applying a choice-based trip distribution model. The choice-based model can incorporate many variables into the trip distribution model; the gravity model is restricted to the number of variables it can incorporate. The choice-based model is more cumbersome to calibrate, but may provide more insight to the trip distribution characteristics.

Should socioeconomic variable(s) be incorporated to trip distribution models?

There are a number of applications of the gravity model and choice-based models for trip distribution that incorporate socioeconomic variables and indicate that incorporating socioeconomic variables does improve the trip distribution model. The tradeoff with the gravity model is the increased number of trip purposes generated from stratifying each purpose by the socioeconomic variable (such as income).

Should the trip distribution model incorporate composite costs?

Composite costs represent a weighted average of the travel times and costs for the available modes in the system. This requires a feedback of these composite costs from the mode choice model.

Should the mode choice model estimate walking and bicycle trips?

The mode choice model should estimate walking and bicycle trips separate from the other trips, as the number of vehicle trips, including intrazonals, is an important input to emissions models. There are some applications of mode choice models in the U.S. which estimate walking and bicycle trips as a post-process, but this practice is not wide-spread in California. Further research could incorporate procedures to estimate bicycle and walk trips into the mode-choice model.

Should mode choice models account for multi-modal trips, such as park-and-ride?

Typically, park-and-ride trips are estimated by the mode choice model as drive access transit trips. The driving portion of these trips should be translated to the highway trip assignment model to account for the congestion and air pollution these trips contribute. Existing software packages do not provide automated procedures for assigning park-and-ride trips to the highway network.

Should trip assignment models use composite costs?

Consistent estimates of composite costs should be used in each of the four-step models. The highway assignment model should reflect highway related travel times and costs, and the transit assignment model should reflect transit travel times and costs, in a similar manner to those costs used in the mode choice model.

5.3.4 Other Research Needs

Can cross-sectional data obtained at a single point in time be used to estimate travel behavior over time?

Typically, models are calibrated with cross-sectional data taken at a particular point in time, and may not be useful in developing models that estimate trip-making behavior over time. (Bates, Dasgupta, 1990) The solution to this issue is costly data collection or further analysis of historical data collection efforts and the historical performance of travel demand models.

How does the size of the transportation system limit the complexity of the model?

The size of urban transportation systems will limit the complexity of the models that can be developed. Considerations to increase the complexity of the models, add variables or feedback loops, or modify existing model structures must be weighed against the resources available to forecast the data and calibrate the existing models.

How does model improvements, and more accurate forecasts, compare to the cost of the improvement and the errors in input data?

Improvements to the four-step travel demand modeling process may increase the ability of the model to estimate travel demand and produce more accurate forecasts, at some cost to implement the improvement. These costs and benefits need to be weighed against the error introduced by using externally dependent forecasts. Some resources could be allocated to more sophisticated techniques to forecast the input data to the travel demand models.

Should travel demand models account for multiple-purpose trips?

Travel demand models may be improved by recognizing the phenomena of trip-chaining and accounting for these multiple-purpose trips. Trip-making behavior is often determined by the multiple-purpose trips, where existing travel demand models estimate single-purpose trips. There is available research on the impacts of trip-chaining (Kitamura, 1983).

Can travel demand models evaluate IVHS and other new technologies?

New technologies such as Intelligent Vehicle Highway Systems (IVHS) will impact the behavior of travelers. The current travel demand models will need to respond to these new technologies by providing models that can adequately test the impacts on the transportation system.

5.4 EMISSION INVENTORY AND OTHER AIR QUALITY RESEARCH NEEDS

Adoption of the Federal Clean Air Act Amendments of 1990 has renewed interest in use of regional travel models in developing emission inventories and in predicting the impact of growth and transportation projects on air quality. While it is generally recognized that regional models are essential in developing the data for air quality analysis, it is also recognized that there are certain limitations in the models that affect the accuracy of the emission estimates produced from their output. If the emission inventories and the air quality analyses are to continue to rely on regional models for travel activity data, new research is warranted to adapt the regional models more specifically to emissions estimation. Such research is warranted in four major areas: 1.) comprehensive coverage of trips, 2.) prediction of starts and parks, 3.) modeling of weekend and summertime travel, 4.) enhancement of emission rates. A brief discussion of each of these areas is provided below.

5.4.1 Comprehensive Coverage of Trips

Because of the importance of trips/starts as a determinant of pollutant emissions, additional research to improve the comprehensive coverage of trips is warranted. With the current round of home interview surveys being conducted around the state, the opportunity exists for an analysis of bias in trip reporting. With the new data there should be an effort to identify each time a vehicle is started, regardless of the length of the trip or the trip purpose. Research with the new data should also explore a better understanding of non-home-based trips, particularly lunch trips, personal errands, business travel, and commercial trips. These are all areas in which there is a significant potential for under-reporting in a home interview survey. More comprehensive coverage of these non-home-based trips in the modeling system will lead not only to better emission inventory estimations, but also to greater sensitivity to demand management policies.

5.4.2 Prediction of Starts and Parks

The representation of starts and parks is an important element of the DTIM model methodology for emission estimation, yet the methodology is based on limited survey data. Additional research on the nature of trips starts and parking duration is warranted and is possible with the new home interview survey data. As the coverage of trip types becomes more comprehensive and shorter trips are included in the activity data, differentiation of hot and cold starts will become more important. In addition, as the tightening of standards reduces the running emissions the trips starts, trip ends, and diurnal emissions will constitute an increasingly larger portion of total emissions.

5.4.3 Modeling of Weekend and Summertime Travel

Recent air quality monitoring in California has indicated that in numerous locations ambient air quality standards have been violated during the summer months and frequently on weekend days. Virtually all regional travel models are designed to represent an average annual weekday, and their usefulness in representing these summertime or weekend conditions is limited. New survey and research leading to the development of models for weekends and summertime travel would significantly enhance the emission inventories for these periods.

5.4.4 Enhancement of Emission Rates

Research now underway at the California Air Resources Board is providing preliminary evidence that there is wide variation in emission rates on a grams-per-mile or a grams-per-hour basis, depending on the operating mode characteristics additional research is needed to relate these emission rates more specifically to the roadway and travel characteristics supplied by the regional travel models. At present emission rates, vary by vehicle type and age, and by average operating speed, but do not vary by facility type or facility characteristics that could produce significant variation in actual emissions for the same average operating speed. As an example, an average operating speed of 30 mph on an arterial might represent free flow without stops, while 30 mph on a freeway would represent congested conditions with frequent accelerations and a significantly higher emission rate. The research on emission rates should lead towards more precise specification of rates using more data from the modeling system.

5.5 TRAFFIC MANAGEMENT AND DEMAND MANAGEMENT ANALYSIS NEEDS

As the opportunities to build new highway facilities or widen existing facilities in congested urban corridors have decreased, focus has shifted to transportation management options to accommodate travel demand. Throughout the state there is increasing interest in high occupancy vehicle facilities such as HOV lanes and ramp meter bypass for high occupancy vehicles. (Traffic management options such as surveillance, incident response, ramp metering, changeable message signs, and signal optimization and numerous demand management options including congestion pricing, parking restrictions, rideshare incentives, and alternative work schedules are being explored.) Many regional models that were sufficiently sensitive for analysis of new facilities or for significant widening of existing facilities are now insufficient for traffic management and demand management analyses. A significant amount of new research and development is needed to improve the sensitivity of regional models to these increasingly popular options.

5.5.1 Traffic Management

Many of the traffic management options achieve their effectiveness by changing the nature and location of delays. And in doing so increase the through-put in a corridor and also reduce the total person hours of delay. Most regional planning models are deficient in their representation of delay and so are insensitive to the measures being considered. The sensitivity to the measures and their impact on delay can often be provided by a variety of simulation models such as NETSIM for arterial systems and FREQ for freeway systems. But these models have serious limitations for regional analysis. To gain the intensive to the traffic management options, the simulation models become highly data sensitive and consume significant computer resources in producing simulations. As a result, only limited areas can be represented in a simulation model. Research is needed to more closely link planning and simulation models to provide more sensitivity to traffic management options while maintaining reasonable resource requirements.

As computing capabilities evolve and simulation algorithms are made more efficient, the opportunities for fully integrating simulation models into the assignment step of the four step modeling process becomes a possibility. This full integration of the simulation and planning models would provide the most complete response to the needs but is unlikely with the existing state of computer technology. Alternatives to this full integration would be automated transfer of data in both directions between planning models and simulation models to reduce the time required for iterations of the two models in analysis of traffic management options. A second alternative would be to develop generalized prototype simulation modules to represent approximate delay as a function of supply and demand characteristics generated by the planning models. If these generalized modules could be embedded within the regional planning model, the planning model output would provide more accurate assignments and a better starting input for simulation models.

5.5.2 Demand Management

Regional travel models could enhance their sensitivity to demand management options such as parking pricing, ridesharing incentives, or alternative work schedules. Existing trip generation distribution and mode split models operate on a basis of aggregate representations of travel time/cost tradeoffs that may not capture the relative influences of the demand management measures. Most current analysis of demand management measures is performed external to regional travel models using sensitivity factors based on reported experience. Quite often this reported experience represents only best efforts rather than a cross section of efforts to implement the demand management option. New data are now available from Regulation 15 in the South Coast Air Quality Management District and from other similar trip reduction ordinances around the state and a new opportunity has emerged for development of policy sensitive travel models. Because of the importance of demand management in maintaining mobility and in reducing pollution levels throughout the state, additional research on the behavioral response to demand management actions is warranted.

5.6 INTERFACE BETWEEN LAND USE AND TRANSPORTATION

With the growing recognition that increasing travel demand from growth cannot be accommodated with new facilities, interest has turned to reducing the amount of new travel from growth by changing the nature of development. There is also concern that the development of new transportation facilities can influence the amount and location of new development and thereby induce growth in travel by the supply of transportation facilities. Both of these are areas in which new research is required if regional forecasting models are to be sensitive to the land use/transportation interaction. The legislation for Congestion Management Programs described in Section 5.1.1 addresses the need for an interface between land use and transportation.

5.6.1 Urban Design Impacts

Efforts to control the amount of new vehicular travel generated by development have generated new designs more oriented towards use of transit or use of non-vehicular modes for short trips. These transit oriented designs (TODs) and pedestrian oriented designs (PODs) are being given increasing consideration in suburban activity centers and in residential developments as well. There is little empirical evidence, however, of the trip reduction impacts of these designs. As TODs and PODs are developed, opportunities for understanding their impacts on travel characteristics become possible. As data become available new model estimation should reflect the impact of design on trip generation, trip distribution, and mode choice to the extent possible.

5.6.2 Transportation's Impact on Land Use

The second significant area of research need is the impact of transportation facilities on land use. There is at least a theoretical basis for the assumption that an improvement in transportation level of service will stimulate new development. There is little empirical evidence, however, that this is true on more than a location-specific basis. There is little evidence to indicate that the supply of transportation facilities or that highway level of service affects the total growth that occurs within a region. And yet the amount and location of development is the most significant determinant of travel demand, and this interaction is worthy of further exploration.